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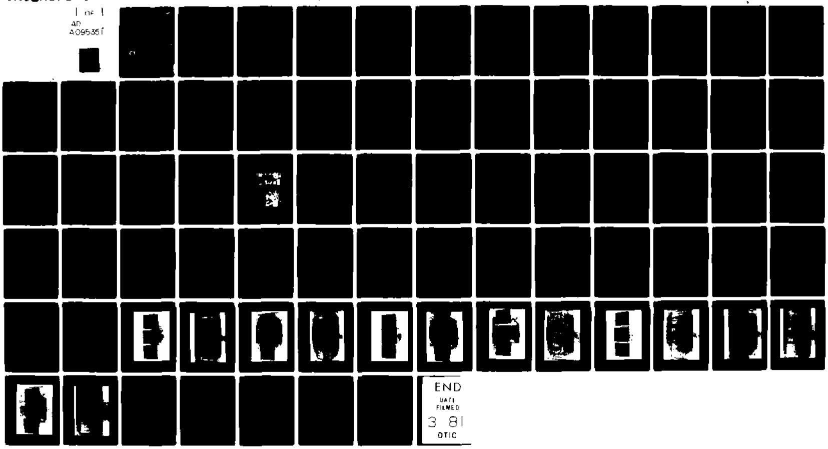

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TECHNICAL REPORT ARLCD-TR-80007

M203 PROPELLING CHARGE RESIDUE INVESTIGATION PART II

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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Part II of the M203 residue problem was initiated because of an unacceptably high frequency of residue in gun firing tests conducted using ambient 21°C (70°F) conditioned charges of lot 79A-06087 with Indramic 170C wax in the wear preventive additive liner. Most instances of residue were observed with tube temperature above 82°C (180°F).

Laboratory investigations and tests leading to a gun firing plan are described.

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20. Abstract (Cont)

Gun firings showed that charges made with Polywax 655, a more brittle wax, produced less residue than any other charge configuration. Factors other than the choice of wax in the liner which increased the frequency of residue were: higher tube temperature and longer chambering time (which softens the wax), rayon and lead laminate as the liner substrate, and increased amounts of dacron staple in the liner. Since these characteristics tend to impede liner breakup, their effect is consistent with the proposed mechanism for residue formation.

Charges made using Polywax 655 with scrim liners have been shown to be free of residue when fired in gun tubes up to 149°C (300°F) with chambering times under 30 seconds.

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TABLE OF CONTENTS

TABLES

FIGURES

INTRODUCTION

During safety testing of the M203E1 propelling charge in July 1978, large fragments of charge residue were observed for charges preconditioned at 63°C (145°F). This residue occurred while firing the latter portion of a 48-round group. The residue consisted of large portions of non-combusted bag, liner, and jacket material which was either loose in the gun chamber or firmly attached to the chamber wall. This residue became a matter of concern when it resulted in the failure of an M549A1 projectile to chamber fully. An investigation was initiated, and it was found that the residue was related primarily to charges preconditioned at 63°C (145°F) and fired in hot tubes [71°C (160°F) and above].

A test program was initiated to determine the cause of the problem and to provide corrective measures. As a result of residue test firings on 24 August 1978 and 6 October 1978 at Jefferson Proving Ground (JPG), it became apparent that the residue problem was common to all the M203 propelling charges produced since December 1977. Subsequent testing concentrated on the M203 charge (in lieu of the M203E1). A detailed report of the test programs, procedures, and results is given in reference 1.

The use of higher-melting-point wax [Indramic 170C, Melting point of 82°C (180°F) instead of Shell 300, Melting Point of 71°C (160°F)] for wear preventing additive liner eliminated residue under the conditions of the tests. Production of the modified M203 charge was initiated during the week of 14 January 1979, a M203 charge lot 79A-69807. A sample group of these charges was drawn from the early production and was shipped to Yuma Proving Grounds (YPG) for ballistic and residue testing. M203 charges from lot 77L-69805 were used as reference charges. Ballistics were within requirements and there were no occurrences of residue. (The final acceptance of lot 79A-69807 later confirmed these results.)

During the firing table test for the M109A1 howitzer in April 1979 at YPG with the M203 charge (lot 79A-69807) preconditioned at 21°C (70°F), residue was observed in 12 of 268 rounds fired. Residue consisted of cloth fragments sticking to the chamber walls and loose cloth fragments in the tube. Most of the fragments were small 19.3 cm^2 (3 sq in.^{2}) or less; however, one was large, 71 cm^2 (11 in.^{2}). Sticking residue was also encountered with M203 charges preconditioned at ambient temperature during production verification testing (PVT) of the M199 cannon at Aberdeen Proving Ground (APG) in May 1979.

The reoccurrence of a residue problem with the M203 propelling charge led to a further investigation. This investigation is designated as Part II and is the subject of this report.

A history of the experience of firing M203 charges with the Indramic 170C wax in the wear preventive additive liner was compiled (table 1). From preliminary evaluations several possible causes of the reoccurrence of residue were postulated:

1. Variation in physical characteristics of the charge (e.g., external dimensions, position of the straps relative to lacing, and lead thickness).

2. Variation in wax characteristics and/or liner manufacture.

3. Effects of climate at time of firing. Although previous testing was in a hot tube [71^{o} to 82^{o} (160^{o} to 180^{o}F)], these firings were the first performed during hot weather at YPG and warm weather at APG. (The occurrence of residue during the PVT test as a function of the date of firing is given in figures 1 and 2. The frequency of residue and maximum tube temperature as a function of the date of firing are given in figure 3.)

4. Variation in ignition characteristics (primer output variation leading to harder or softer ignition).

Thirty charges were withdrawn from each inventory of lot 79A-69807, at APG, JPG, and YPG. Three charges from each of these groups of thirty were torn down and the inert components shipped to ARRADCOM.

Since production variables were first suspected as the cause of the problem, the following plan was developed to assess this possibility:

1. Investigation at Indiana AAP to determine possible manufacturing variations which might have contributed to the residue problem.

2. Laboratory investigation of production variations, consisting of:

a. Physical assay of overall charge dimensions and physical properties of cloth components.

b. Determination of wear preventing additive liner composition and wax variability.

c. Determination of igniter variability.

3. Gun firings of modified M203 charges to:

a. Test the results of items 1 and 2 above.

b. Test alternate charge designs, particularly liner variations.

RESULTS OF INVESTIGATIONS AND TESTS

Investigation of Manufacturing Variations

The major results and conclusions concerning manufacturing variations at Indiana AAP were:

1. Component orientation to minimize material overlap could be introduced during manufacture without major difficulty and should be implemented.

2. Liner thickness variation occurs during production of liners by the batch process. Variations in thickness of as much as a factor of two from center to edge were observed. More uniform liners can be produced by the continuous process, particularly if the lead-rayon laminate carrier is used.

3. Stearyl alcohol (advisory in the specification) was omitted from the wax/-TiO_2 mix during the last half of lot 79A-69807 production. A determination should be made as to how this omission affects liner properties and residue occurrence.

4. Observations of varying coloration of wax samples drawn from a single shipment of Indramic 170C strongly suggested non-homogeneity in the wax as received. Samples were shipped to Holston AAP and to ARRADCOM, Dover for further analyses.

Laboratory Analyses

The results of the physical assay are detailed in appendix A. Although some of the thread counts and cloth strengths were found to be outside the specifications, no clear correlation with the occurrence of residue could be established. However, it was noted that in some instances more material overlap occurs within the charge; e.g. tie straps coinciding with bag seam and gusset. It is possible to have a maximum of nine layers of material at one location. Also, variations in liner thickness were noted.

Appendix A outlines the laboratory investigation procedures and results. While there is measured variability in the Indramic 170C wax and liners made using this wax (lot 79A-69807), it was not possible to discern any significant difference between early and late production. The liners appeared to be the same, within the measurement error, as those used in previous testing of Indramic 170C (ref 1). In addition, an apparently intact liner fragment, taken from residue in the gun chamber during 15 May 1979 PVT of lot 79A-69807 showed no differences. However, the dacron content exceeded the specified maximum of 0.75% in many cases (in one case, sample APG3, the dacron content was 2.3%). Also, exudation from the liners exceeded the specified maximum of 2.5% for every sample measured.

The laboratory analyses suggested that the high dacron content and high exudation of the Indramic 170C liners be investigated as a source of residue. The high exudation could only be reduced by a change in the wax. A more detailed study of wax for use in liners was undertaken at this time (ref 2). Standard wax specification tests (MIL-W-20553D) were performed, and the melting characteristics of various waxes was examined in detail. Samples of the Indramic 170C used for lot 79A-69807, Shell 300 wax (used prior to the 1979 production), and two low-molecular-weight polyethylene synthetic waxes, Bareco Polywax 500 and 655 were analyzed.

One of the most informative specification tests for waxes is the differential scanning calorimetry (DSC) test. This test essentially measures the heat gained or released by a sample relative to a standard, when its temperature is changed at a predetermined, constant rate. To compare the fractional melting of the various waxes, the normalized integral of the DSC trace up to a given temperature is given as a function of temperature (fig. 4).

Analysis of DSC data also yields the initial melting and liquefication points and the heat of fusion. These values are listed in table 2 for the four waxes being considered, along with the drop melting point and penetration distance. Penetration distance is the distance which a specially prepared, weighted needle sinks into the wax at a given temperature in a given time, measured in units of 0.1 mm. Penetration data were obtained according to procedures in ASTMD-1321.

Gun Firings

Based on the results of the investigation at Indiana AAP and the laboratory analyses, a gun firing test was devised. The groups in this test had the same charge configuration as used in lot 79A-69807 (table 3). This test was conducted in June 1979 at JPG[1]. A decision was made to fire half of each 30-round group with tube temperatues below 82°C and to fire the other half with tube temperatures above 82°C. Results of this firing test are shown in tables 4 to 6.

A second firing test was devised based on the results of the first firing test results. Since Polywax 655 liners performed best in the first firing test and since tube temperature was shown to be an important variable, the second firing test was designed to evaluate Polywax 655 with scrim (group U) and Polywax 655 with rayon/lead laminate (group V) as a function of tube temperature up to 149°C (300°F). Lot 79A-69807 was used as a control. Groups of charges conditioned at -54°, 21°, and 63°C were tested over a wide range of tube temperatures. In addition, the residence time of the charge in the gun chamber prior to firing was recorded and in some cases the charges were intentionally chambered for excessively long times.

The second firing test was conducted at JPG in July 1979[2,3]. The gun tube was preheated by an oil-fired burner (fig. 5). (This method had been used successfully at YPG during similar tests of the 8-inch M188E1 propelling charge.) The results as a function of tube temperature and chambering time are shown in figures 6 through 11 and in tables 7 through 9. Charges subjected to logistical transportation and rough handling tests were also fired (app B).

DISCUSSION

Residue Frequency

The Part II M203 residue problem consisted of an unacceptably high frequency of residue in tests conducted using ambient or 21°C (70°F) conditioned charges. The reoccurrence of the residue problem was largely responsible for a delay in plans to transition the M203 charge from PM-CAWS to ARRCOM for production.

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[1]D. Ellington, et al, Trip Report, JPG, 27 August 1979

[2]L. Harris and K. Russell, Trip Report, JPG, 9 July 1979.

[3]D. Downs and D. Ellington, Trip Report, JPG, 17 July 1979

The frequency of occurrence of residue was most carefully observed, over a long period of time, during PVT of the M198 howitzer at APG. The M203 charges fired in the PVT were from lot 79A-69807. which was the first lot using Indramic 170C in the wear preventing additive liner. In May 1979 (fig. 3) the frequency was much greater than in the period February to April 1979.

In the Part I residue test, the use of Indramic 170C resulted in acceptable performance with minimal residue when charges conditioned at 63°C (145°F) fired from tubes having temperatures ranging from 71° to 82°C.

The frequency of occurrence of residue shown in figure 3 is for ambient charges fi ·d from tubes hotter than 82°C (180°F) which is outside the range · conditions tested in Part I of the residue investigation (160° to 180°F). The results of the first firing test also show an increased frequency of residue for the Indramic 170C (lot 79A-69807) in hot tubes [temperatures greater than 82°C (180°F). In evaluating groups U and V the temperatures for both charge conditioning and gun tube were varied over as wide a range as possible. The residence time of the charge in the gun chamber was also varied. The results of the gun firing can be summarized as follows:

1. For Polywax/scrim charge conditioned at 21°C (70°F) no residue is observed for gun tube temperature up to 138°C (280°F) when the round is chambered for less than 70 seconds. Longer chambering times (up to 3 minutes) result in increased residue. The Polywax/laminates give somewhat more residue than Polywax/scrim. Both Polywax variations show substantial improvements over Indramic 170C (lot 79A-69807).

2. Both Polywax variations give substantially less residue per round than the Indramic 170C (table 7). For charges conditioned at 21°C (70°F), Polywax/scrim produce somewhat less residue than Polywax/laminate.

Heat Input and Ballistic Data

Heat input and ballistic data for both gun firings are given in table 10. At comparable gun tube temperatures, the mean heat input for the charges with Polywax 655 in the liner group U is within a standard deviation of the mean heat input for the standard charges with Indramic 170C (lot 79A-69807). (The effect of initial gun tube temperature on the measured heat input value is discussed in reference 3.) On this basis gun tube wear for the charges with Polywax 655 in the liner is predicted to be no worse than that for the charge with Indramic 170C in the liner. The ballistic data are all within the specification for the M203.

CONCLUSIONS

1. The results of gun firings with Polywax 655 charges and Indramic 170C charges are consistent with the proposed mechanism in reference 1, that a more brittle wax enhances wear additive liner breakup, resulting in a decrease in residue. The polywax/scrim charges performed somewhat better than the polywax/laminate charges, because the stronger liner impedes liner breakup.

2. The Polywax 655/scrim charges have the following advantages over Indramic 170C charges:

a. There is no residue with 21°C (70°F) conditioned Polywax 655 charges when the chambering time is less than 1 minute and the gun tube temperature is ambient to 138°C (280°). Under the same conditions, Indramic 170C charges give a residue frequency of at least 40% when the gun tube temperature is greater than 93°C (200°F).

b. There is some residue with 63°C (145°F) conditioned Polywax 655 charges. However, the frequency is lower than with Indramic 170C and the average amount of residue is less than 1 gram per round with gun tube temperatures of ambient to 149°C (300°F). Indramic 170C produced an average of 34 grams of residue per round when the gun tube was heated above 82°C (180°F).

3. Polywax 655/scrim liners were also shown to perform successfully in the logistical transportation and rough handling tests (app B). The tube wear produced with polywax/scrim liners was estimated (using heat input values from the Calspan test) to be no worse than that of Lot 79A-69807. On the basis of the improved residue performance with no decrement in other areas of performance, Polywax 655 was recommended as a replacement for Indramic 170C in the M203 charge. Polywax has the additional advantage that it is a synthetic and therefore does not depend on petroleum refining procedures. Quality control of the synthetic way should present much less of a problem.

4. Lastly, the parameters controlling the occurrence of residue were shown to be the initial charge temperature, the temperature of the gun chamber, and the residence time of the charge in

chamber prior to firing. All of these factors influence the brittleness of the liner prior to firing. Based on the study a warning statement has been included in the M198 howitzer operator's manual. This statement cautions against the possible occurrence of residue after long chambering times.

RECOMMENDATION

It was recommended that the technical data package for the M203 charge be modified to specify Bareco Polywax 655. This recommendation was followed, and the M203 charge was transitioned to ARRCOM in December 1979.

REFERENCES

1. D. S. Downs, L. Harris, and K. Russel, "M203 Propelling Charge Residue Investigation, Part I," Technical Report ARLCD-TR-80006, ARRADCOM, Dover, NJ (in press).

2. D. S. Downs and L. E. Harris, "Relationship of Residue Formation to Wax Used on M203 Propelling Charge Liners," Technical Report ARLCD-TR-79042, ARRADCOM, Dover, NJ, December 1979.

3. D. S. Downs, J. A. Lannon, L. E. Harris, G. Sterbutzel, F. Vassallo, and A. Ashby, "Wear Additive Analysis of Charges Used in Artillery Systems," 1980 JANNAF Propulsion Meeting, vol I, CPIA Publication 315, March 1980, p. 123.

Table 1. Occurrence of residue, M203 charge - Indramic 170C

Date	Lot	Temperature °C	Temperature °F	Test	Cannon	Rounds fired	Residue
Nov 78	IS-036 (69806)	145	63	Residue	M199	15	None
Dec 78	IS-068 (69807)	70	21	Residue	M199	15	2 (small)
		145	63	Residue	M199	15	None
Jan 79	79A-69807	70	21	Ballistics	M199	15	None
		-65	-54	Ballistics	M199	20	None
		+145	63	Ballistics	M199	25	None
Mar 79	79A-69807	70	21	Prop acceptance	M199	15	1 (small)
		-65	-54	Prop acceptance	M199	20	None
		+145	63	Prop acceptance	M199	25	1 (small)
Mar 79	P00035, 36, & 37	70	21	Pilot lot	M199	57	None
		-65	-54	Pilot lot	M199	30	None
		+145	63	Pilot lot	M199	30	None
Mar 79	79A-69807	-65	-54	Spindle (JPG)	M185	100	None
		+145	63	Spindle (JPG)	M185	96	None
Jan-Mar 79	79A-69807	70	21	Projectile test	M199	626	None
		+145	63	Projectile test			
		-65	-54	Projectile test			
Mar-Apr 79	79A-69807	+70	21	PVT	M199	2262	6*
Apr 79	79A-69807	-65	-54	Safety	M185	250	None
		+145	63	Safety			
Apr 79	RAD-69959	70	21	Prop acceptance	M199	19	None
		+145	63	Prop acceptance	M199	13	None
		-65	-54	Prop acceptance	M199	10	None
Apr 79	79A-69807	70	21	M109A2 firing tables	M185	212	11

*One failure to ram; no swabbing.

Table 2. Characteristics of liner waxes

Wax	Initial melting point (°C)	Initial melting point (°F)	Liquefaction point (°C)	Liquefaction point (°F)	Heat of fusion J/kg x 10^{-3}	Heat of fusion cal/g	Penetration distance at 43°C (110°F) (0.1 mm)	Drop melting point (°C)	Drop melting point (°F)
Shell 300	12	54	76	169	208.5	49.8	30	71	160
Indramic 170C	3	37	91	196	177.9	42.5	45	80	176
Polywax 500	12	54	97	207	233.6	55.8	21	88	191
Polywax 655	13	55	109	229	246.6	58.9	7	102	211

Table 3. Variations in liners used in gun firing test

Description	Group
Dark Indramic 170C, no stearyl alcohol	A
Light Indramic 170C, no stearyl alcohol	B
Blend of light and dark Indramic 170C, no stearyl alcohol	C
Blend of light and dark Indramic 170C, with stearyl alcohol	D
Blend of light and dark Indramic 170C, with stearyl alcohol and with other modifications:	
High dacron (2.5%)	E
50% weight increase (thicker liner)	F
Rayon/lead laminate (instead of scrim)	G
Kerr-McGee TiO_2* (instead of duPont TiO_2)	H
Polywax 500, with scrim	I
Polywax 500, with rayon and lead laminate	J
Polywax 655, with scrim	K
Polywax 655, with rayon and lead laminate	L

*This group resulted from a suggestion that Kerr-McGee TiO_2 might have a better controlled particle size distribution than duPont TiO_2.

Table 4. Results of first gun firing test of M203 charge variations with tube temperature less than 82°C (180°F)

Group[a]	Tube temperature °C	(°F)	Rounds with residue
A	28-53	82-127	0
B	54-74	129-166	2
C	56-82	150-180	1
D	-	-	(not fired)
E	73-79	164-174	9
F	58-78	136-172	1
G	32-59	89-139	1
H	31-56	88-132	0
I	61-76	142-168	1[b]
J	28-54	82-129	0
K	74-77	166-170	0
L	56-72	132-162	1[c]

[a]Fifteen rounds fired for each group.

[b]Fragment 2.5 x 5.0 cm (1 x 2 in.).

[c]Fragment 1.25 x 5.0 cm (1/2 x 2 in.).

Table 5. Results of first gun firing test of M203 charge variations with tube temperature greater than 82°C (180°F)

Group[a]	Tube temperature °C	Tube temperature (°F)	Rounds with residue
A	100-109	212-229	7
B	90-101	194-213	11
C	81-93	178-200	3
D	77-96	172-204	10
E	-	-	-
F	86-92	187-198	9
G	92-98	198-208	12
H	93-102	199-216	11
I	85-102	185-215	1[b]
J	104-111	219-231	9
K	79-88	175-191	0
L	98-106	209-223	0

[a]Fifteen rounds fired for each group.

[b]Fragment 2.5 x 5.0 cm (1 x 2 in.).

Table 6. Summary of residue frequency from first gun firing test

Group	Type of liner	Rounds with residue/ rounds fired	Frequency (%)
A, B. C, and D	Indramic 170C with scrim	34/120	28
I	Polywax 500 with scrim	2/30	6
K	Polywax 655 with scrim	0/30	0
L	Polywax 655 with rayon and lead laminate	1/30	3

Table 7. Results of second gun firing test of M203 charge variations with tube temperature less than 82°C (180°F)

Group	Conditioning Temperature (°C)	Conditioning Temperature (°F)	Rounds fired	Rounds with residue: Greatest dimension longer than 3.75 cm (1 1/2 in.)	Rounds with residue: Greatest dimension shorter than 3.75 cm (1 1/2 in.)
79A-69807 (Indramic 170C)	21	70	10	0	1
	63	145	5	0	1
U (Polywax 655 with scrim)	-51	-60	15	0	1
	21	70	45	0	0
	63	145	15	0	1
V (Polywax 655 with rayon and lead laminate)	-51	-60	15	0	0
	21	70	15	0	1
	63	145	15	0	5

Table 8. Results of second gun firing test of M203 charge variations with tube temperature greater than 82°C (180°F)

Group	Conditioning Temperature (°C)	Conditioning Temperature (°F)	Rounds fired	Rounds with residue: Greatest dimension longer than 3.75 cm (1 1/2 in.)	Rounds with residue: Greatest dimension shorter than 3.75 cm (1 1/2 in.)
79A-69807 (Indramic 170C)	21	70	25	10	3
	63	145	10	1	1
U (Polywax 655 with scrim)	21	70	44	2	3
	63	145	45	3	8
V (Polywax 655 with rayon and lead laminate	21	70	60	3	5
	63	145	45	7	12
U (Polywax 655 with scrim)*	-51	-60	4	0	0
	63	+145	4	0	0
V (Polywax 655 with rayon and lead laminate)*	-51	-60	4	1	0
	63	+145	4	1	0

*Subjected to transportation vibration and rough handling tests prior to firing.

Table 9. Average weight of residue per round and frequency of occurrence*

Group	Conditioning Temperature		Tube temperature less than 82°C (180°F)		Tube temperature greater than 82°C (180°F)	
	(°C)	(°F)	Frequency (%)	Avg weight (g)	Frequency (%)	Avg Weight (g)
79A-69807 (Indramic 170C)	21	70	10	<1	40	2.2
	63	145	20	<1	20	33.9
U (Polywax 655 with scrim)	21	70	0	-	7	<1
	63	145	7	<1	22	<1
V (Polywax 655 with rayon and lead laminate)	21	70	7	<1	13	<1
	63	145	33	<1	39	<1
A, B, C, and D	21	70	15	3.2	42	3.2

*One gram of cloth residue is approximately 37.5 cm^2 (6 $in.^2$).

Table 10. Heat input and ballistic data for gun firing tests at JPG, July 1979

Conditioning	Tube temperature range (K)	Rounds fired	Avg Heat input ($J/m^2 \times 10^{-4}$) Thermocouple 1	Thermocouple 2	Avg pressure (MPa)	Avg velocity (m/sec)
Control group (79A-69807)						
Charges conditioned at 294 K (70°F):	325 - 336	10	118 ± 5	120 ± 4	320 ± 4	829.7 ± 1.9
	356 - 365	10	107 ± 6	110 ± 6	322 ± 3	830.0 ± 1.9
	380 - 381	5	105 ± 3	113 ± 2	313 ± 3	830.0 ± 2.2
	405 - 410	5	96 ± 3	98 ± 2	311 ± 4	826.5 ± 1.8
	417 - 418	5	106 ± 6	109 ± 4	323 ± 4	826.8 ± 2.3
Charges conditioned at 336 K (145°F):	355 - 356	5	98 ± 2	105 ± 5	376 ± 3	856.0 ± 2.4
	367 - 389	5	111 ± 1	107 ± 3	381 ± 3	859.9 ± 2.2
Modified M203 (Polywax 655 with scrim)						
Charges conditioned at 336 K (145°F):	303 - 327	15	127 ± 8	137 ± 6	380 ± 7	868.1 ± 3.6
	356 - 360	15	103 ± 3	106 ± 3	378 ± 5	860.3 ± 1.7
	380 - 411	8	106 ± 5	105 ± 6	376 ± 6	860.8 ± 1.7
	397 - 399	7	106 ± 10	91 ± 8	372 ± 4	859.1 ± 1.9
	402 - 410	10	96 ± 3	92 ± 5	378 ± 5	861.9 ± 2.7
	413 - 422	5	91 ± 3	103 ± 7	380 ± 4	860.3 ± 2.6

Table 10. Heat input and ballistic data for gun firing tests at JPG, July 1979 (Cont)

Conditioning	Tube temperature range (K)	Rounds fired	Avg Heat input ($J/m^2 \times 10^{-4}$) Thermocouple 1	Avg Heat input ($J/m^2 \times 10^{-4}$) Thermocouple 2	Avg pressure (MPa)	Avg velocity (m/sec)
Modified M203 (Polywax 655 with scrim) (Cont)						
Charges conditioned at 294 K (70°F):	303 - 324	15	122 ± 5	125 ± 7	311 ± 3	829.4 ± 1.4
	377 - 381	15	112 ± 6	118 ± 10	308 ± 5	826.1 ± 2.2
	380 - 398	12	97 ± 6	105 ± 10	308 ± 2	825.7 ± 1.8
	408 - 413	15	112 ± 6	112 ± 7	308 ± 4	824.6 ± 2.7
Charges conditioned at 222 K (-60°F):	315 - 332	15	119 ± 4	121 ± 4	291 ± 4	789.6 ± 2.2

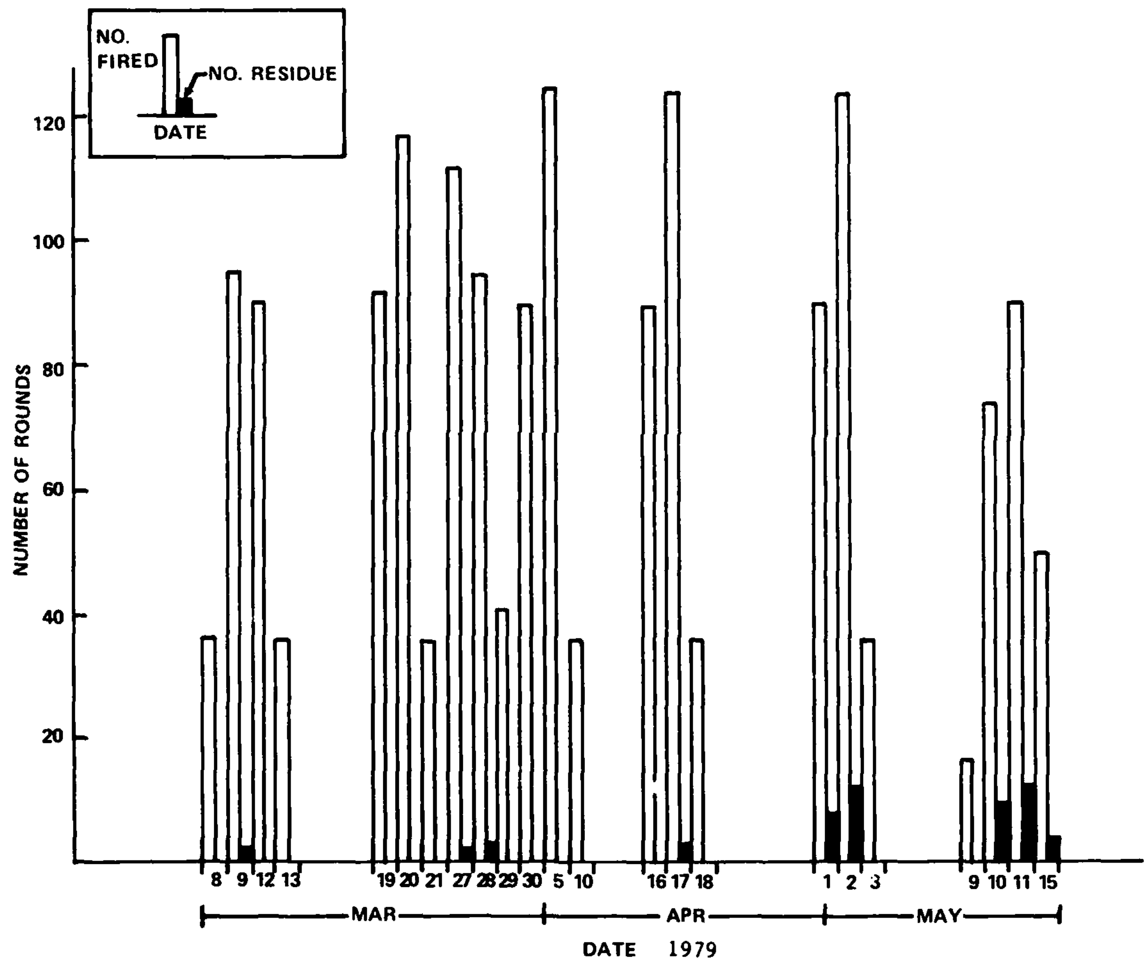


Figure 1. Occurrence of residue during PVT of M198 howitzer -- M203 charges (lot 79A-69807, Indramic 170C), steel tube

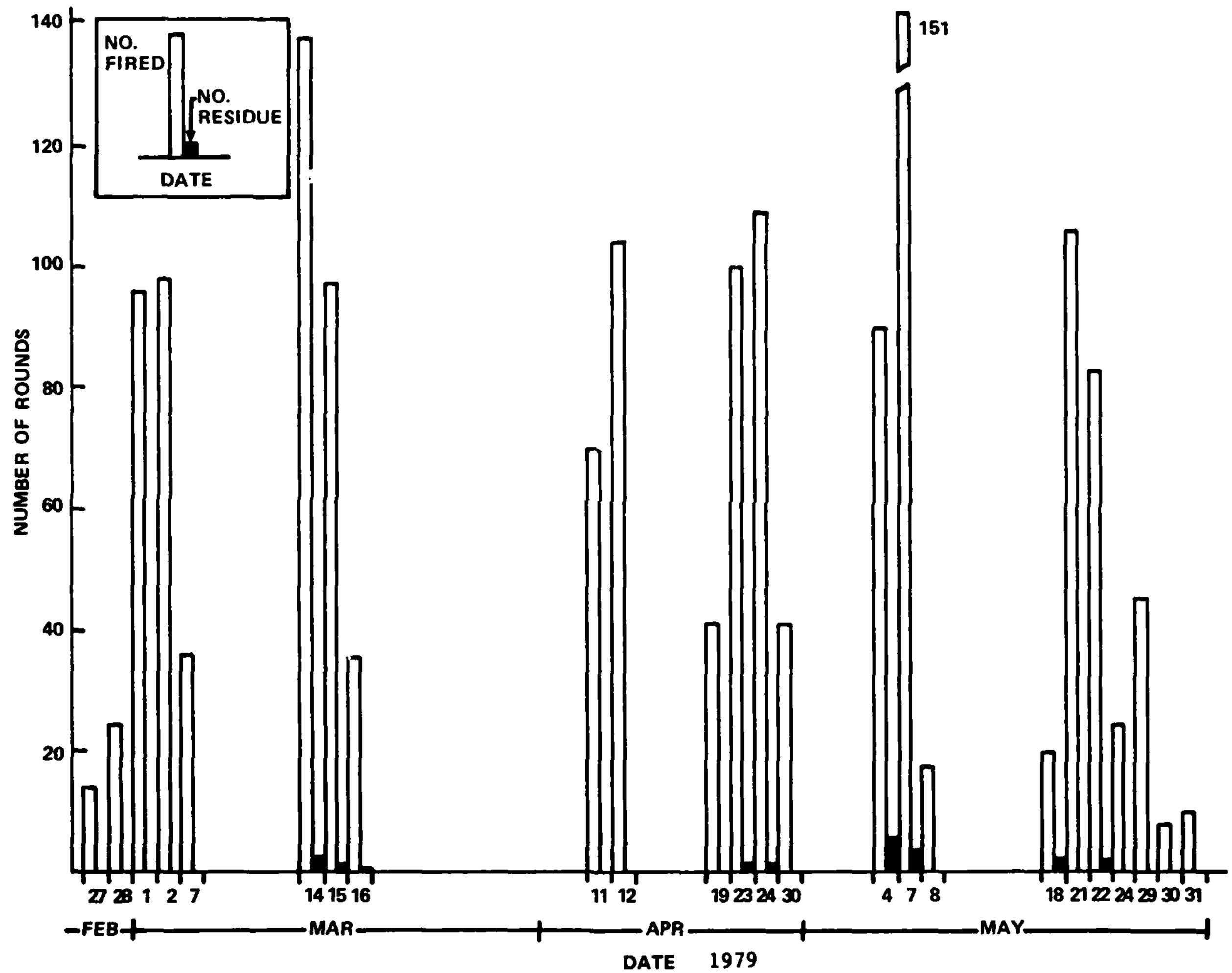


Figure 2. Occurrence of residue during PVT of M198 howitzer -- M203 howitzer (lot 779A-69807, Indramic 170C), chrome plated tube

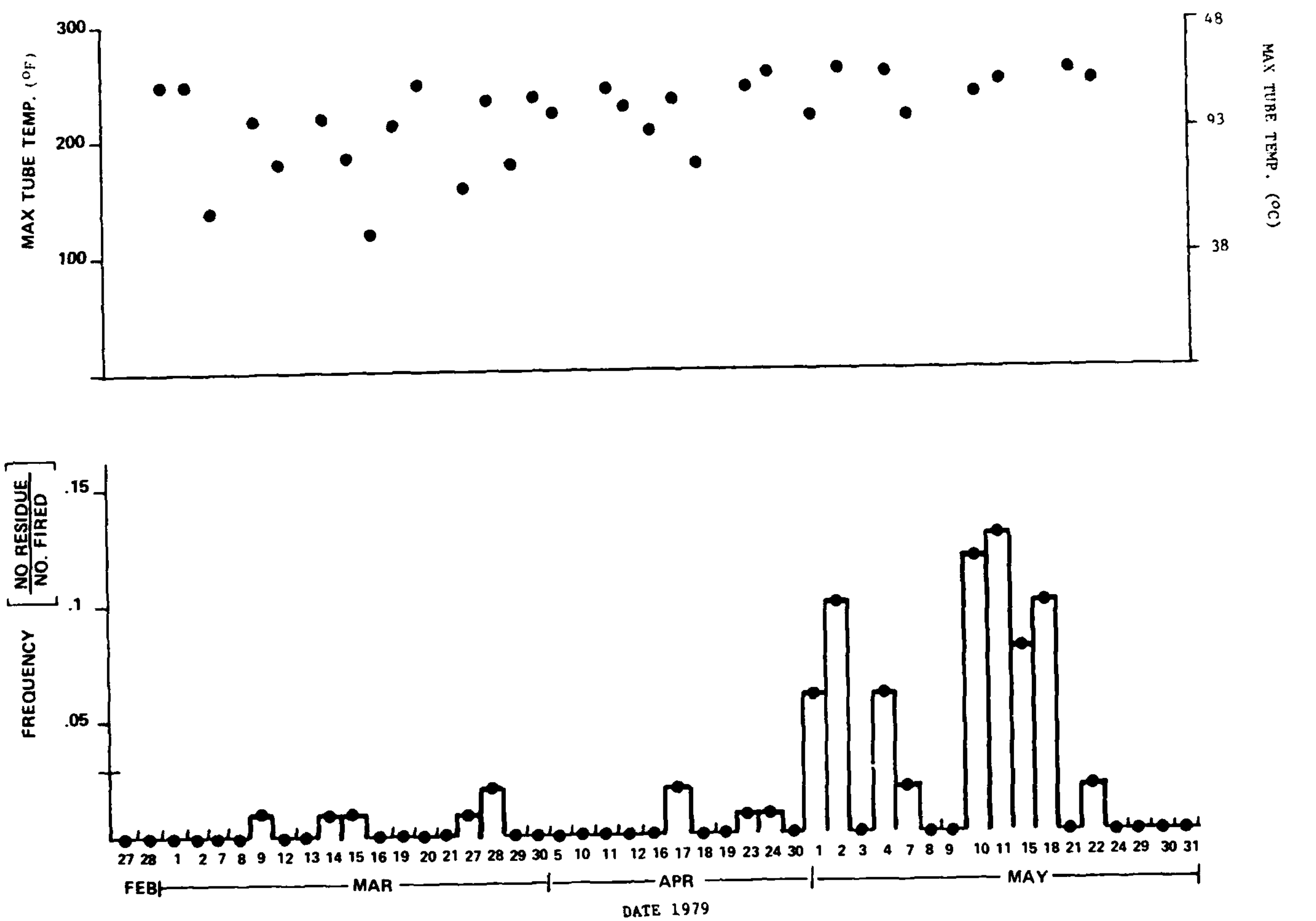


Figure 3. Residue frequency and maximum tube temperature vs date — M203 charges (lot 79A-69807), PVT for the M198 howitzer

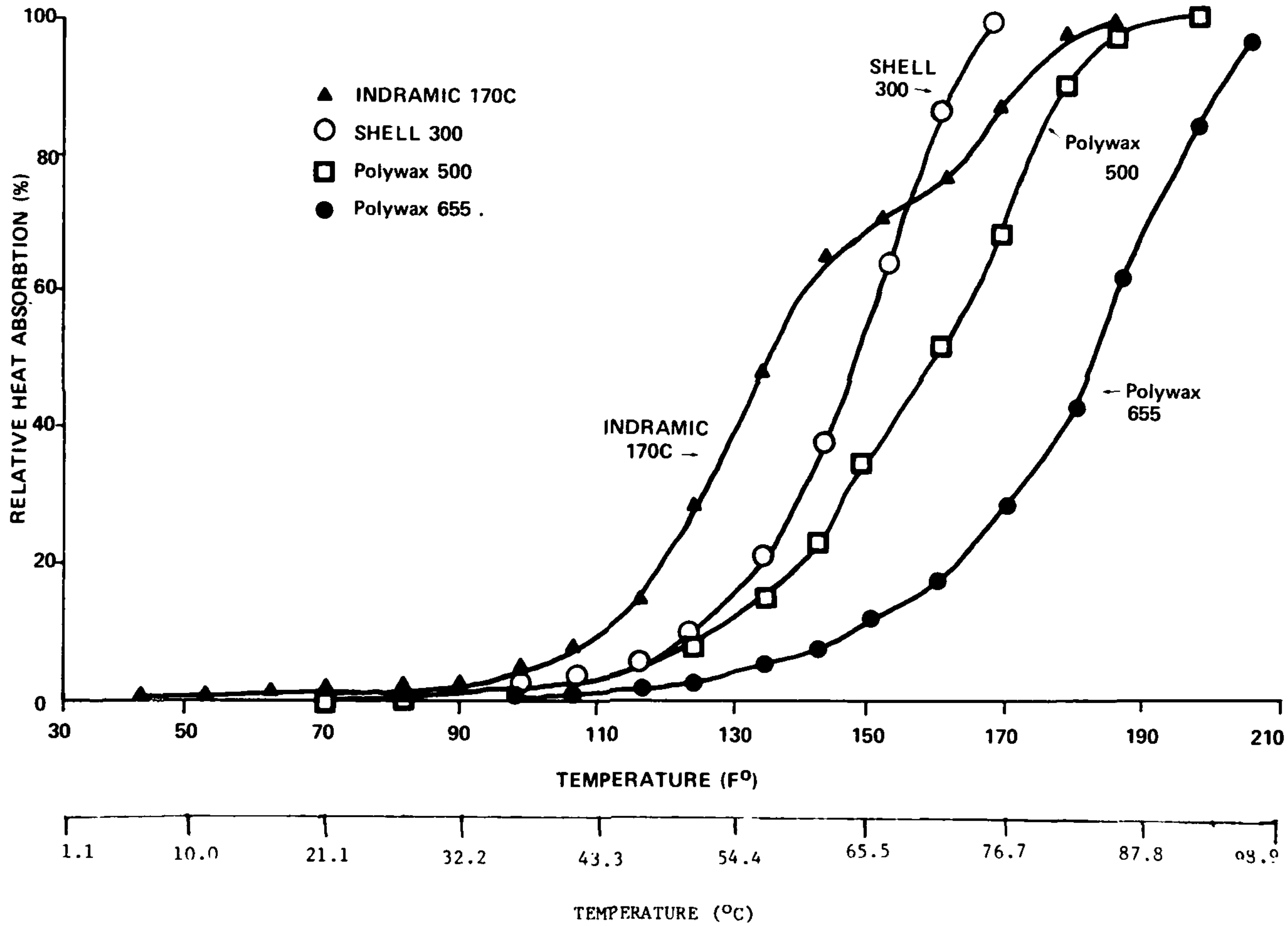
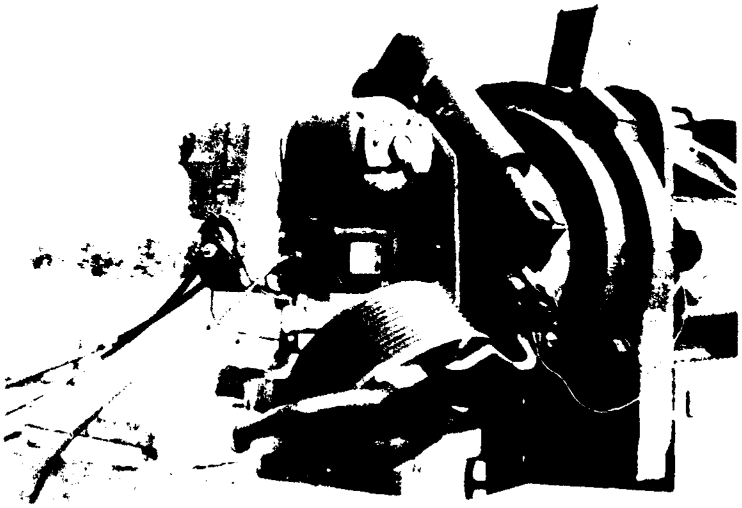


Figure 4. Relative heat absorption vs temperature for liner waxes

VIEW A. BEFORE EMPLACEMENT



VIEW B. AFTER EMPLACEMENT

Figure 5. Gun tube heater

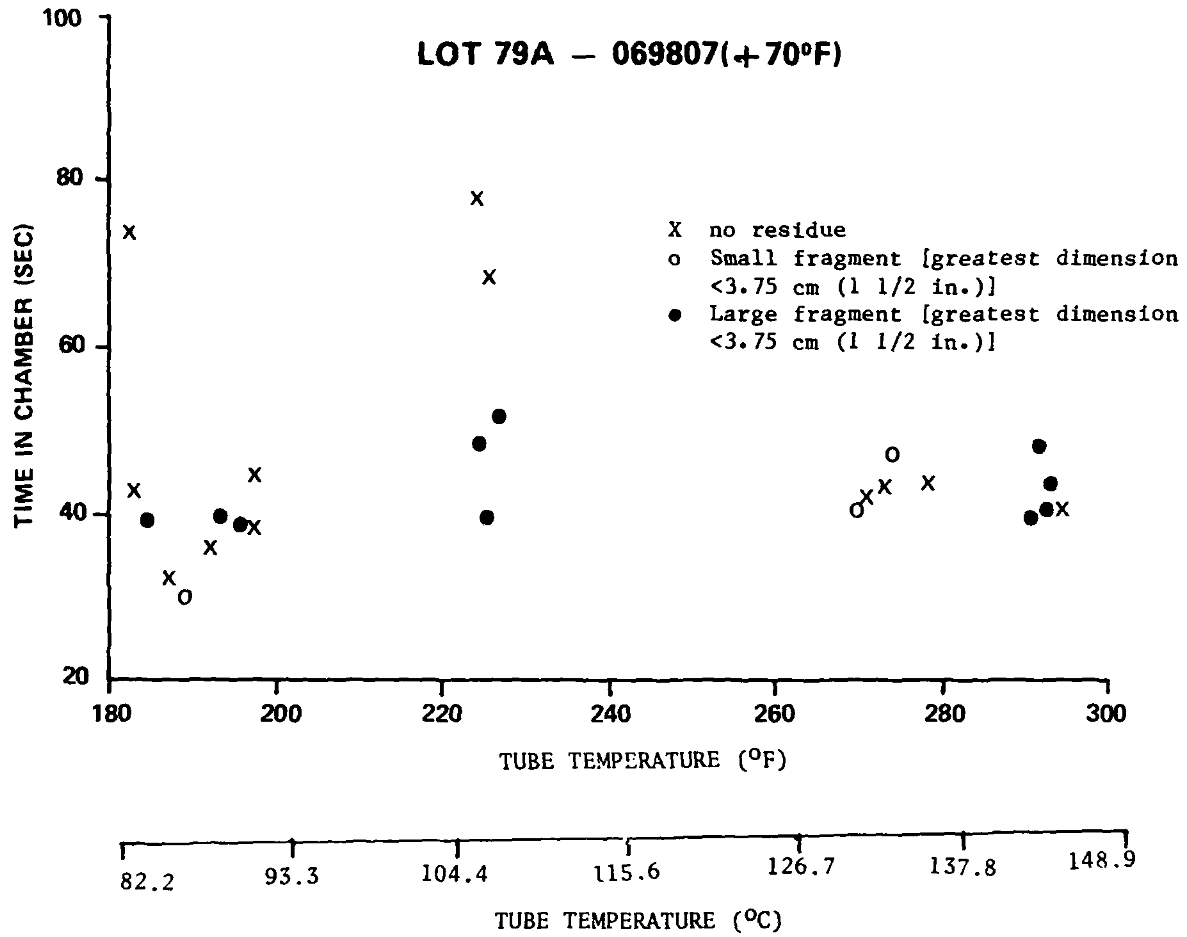


Figure 6. Chamber residence time, tube temperature, and occurrence of residue for Indramic 170C at 21°C (70°F)

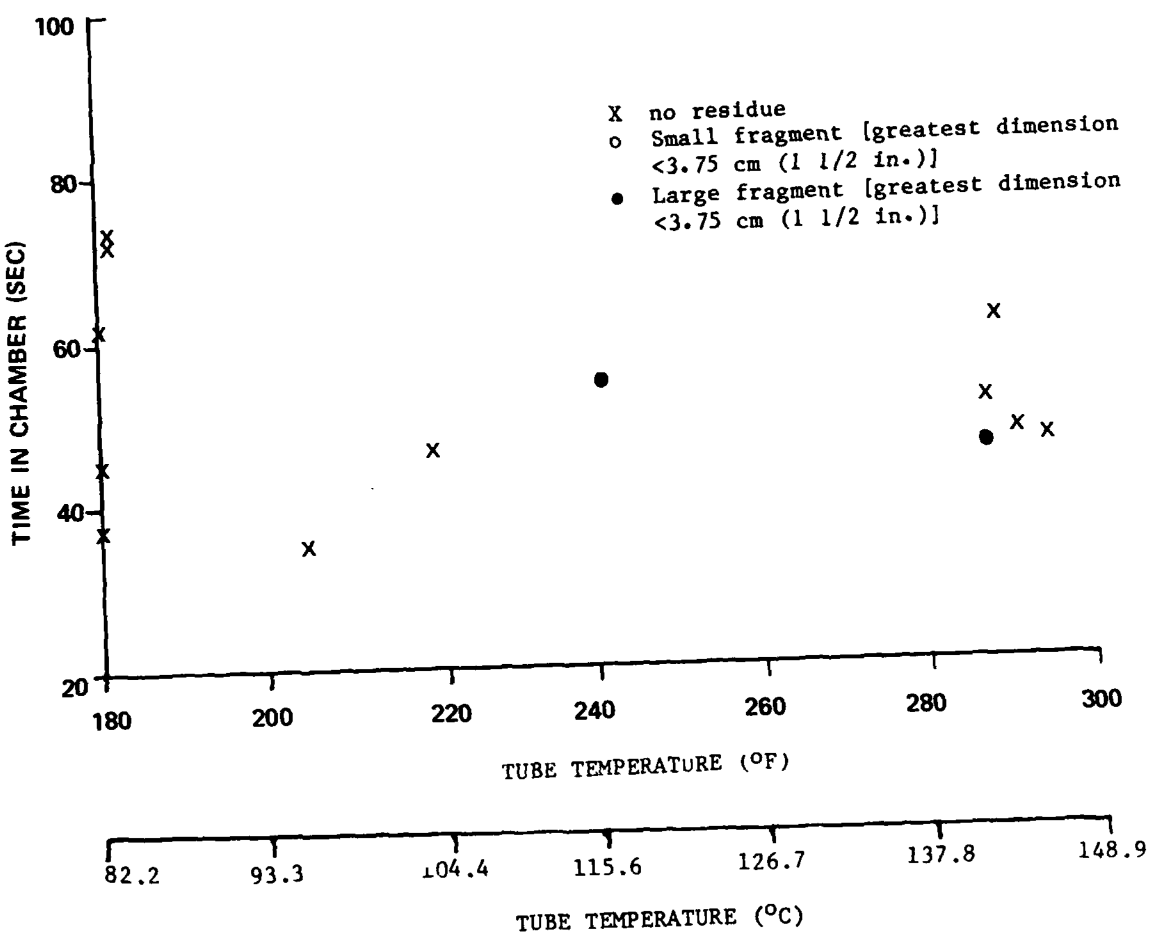


Figure 7. Chamber residence time, tube temperature, and occurrence of residue for Indramic 170C at 63°C (145°F)

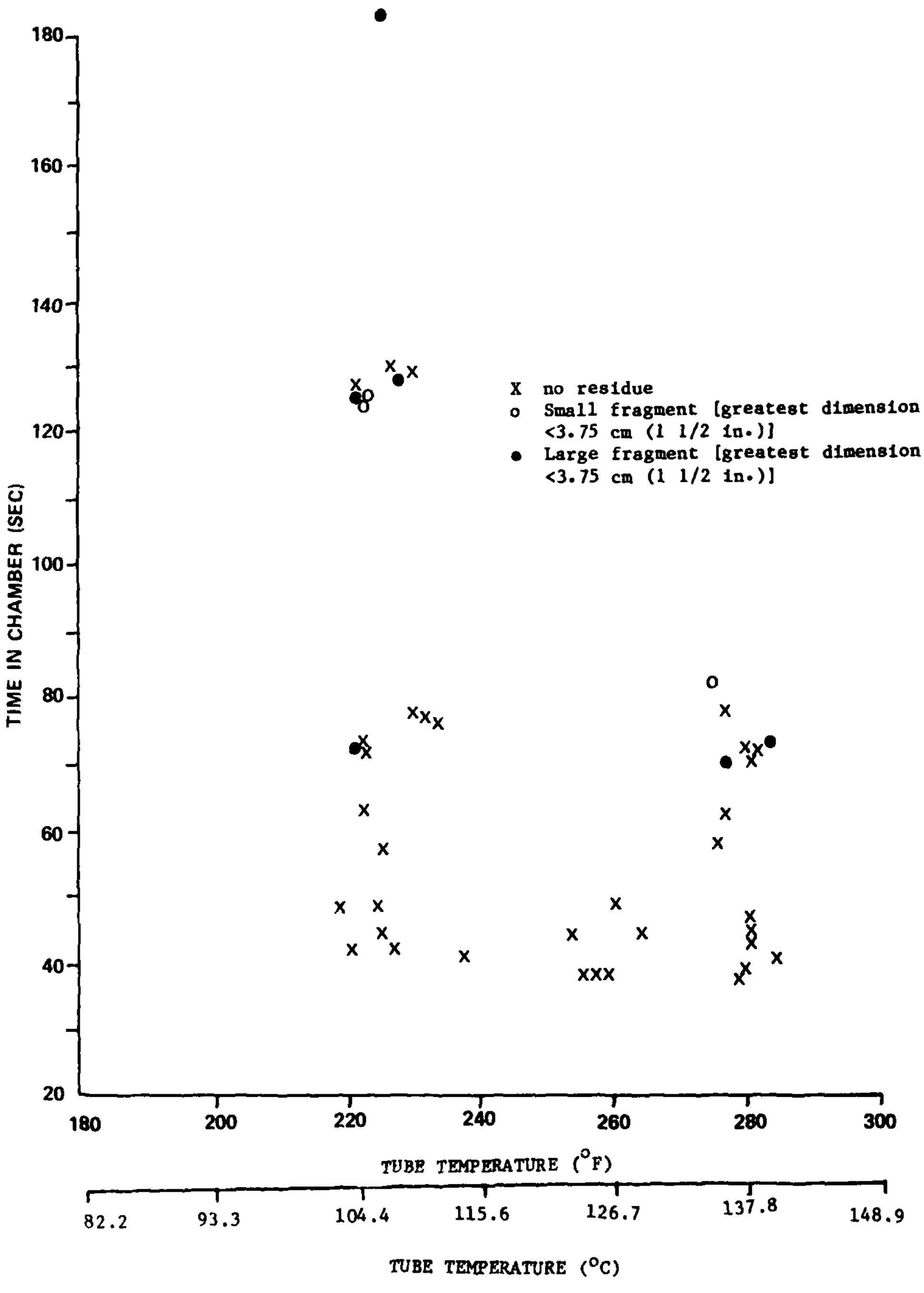


Figure 8. Chamber residence time, tube temperature, and occurrence of residue for Polywax 655 with scrim at 21°C (70°F)

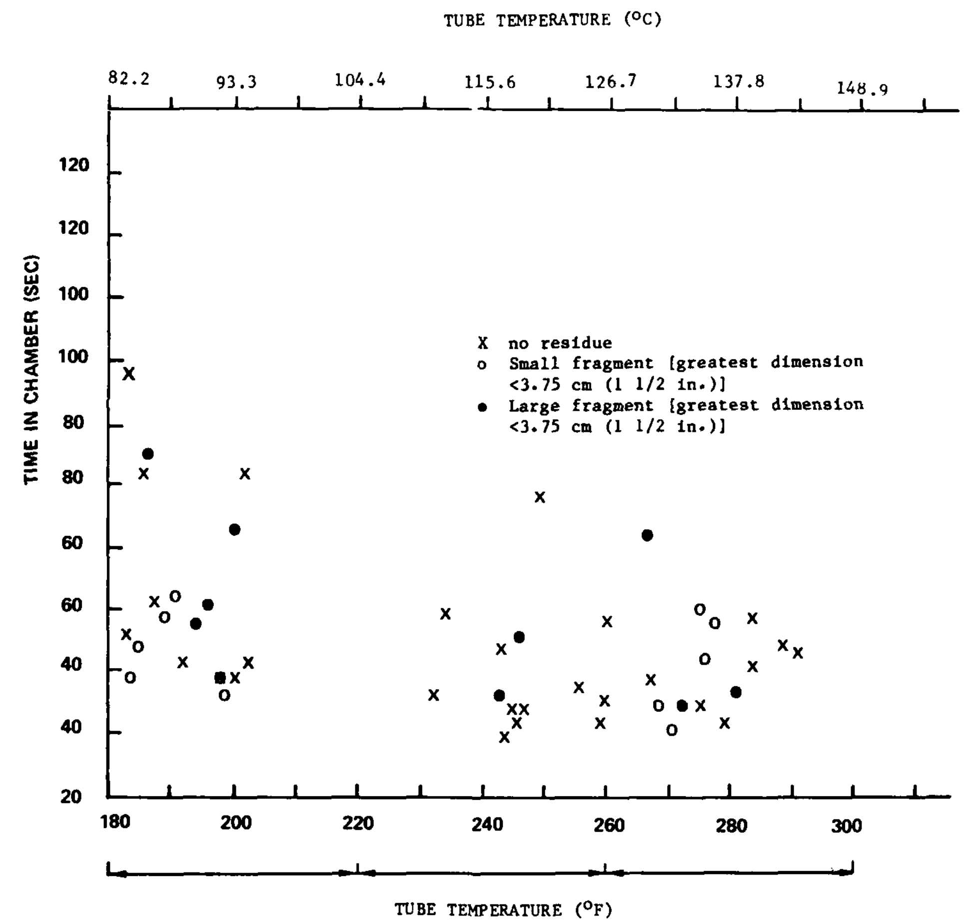


Figure 9. Chamber residence time, tube temperature, and occurrence of residue for Polywax 655 with scrim at 63°C (145°F)

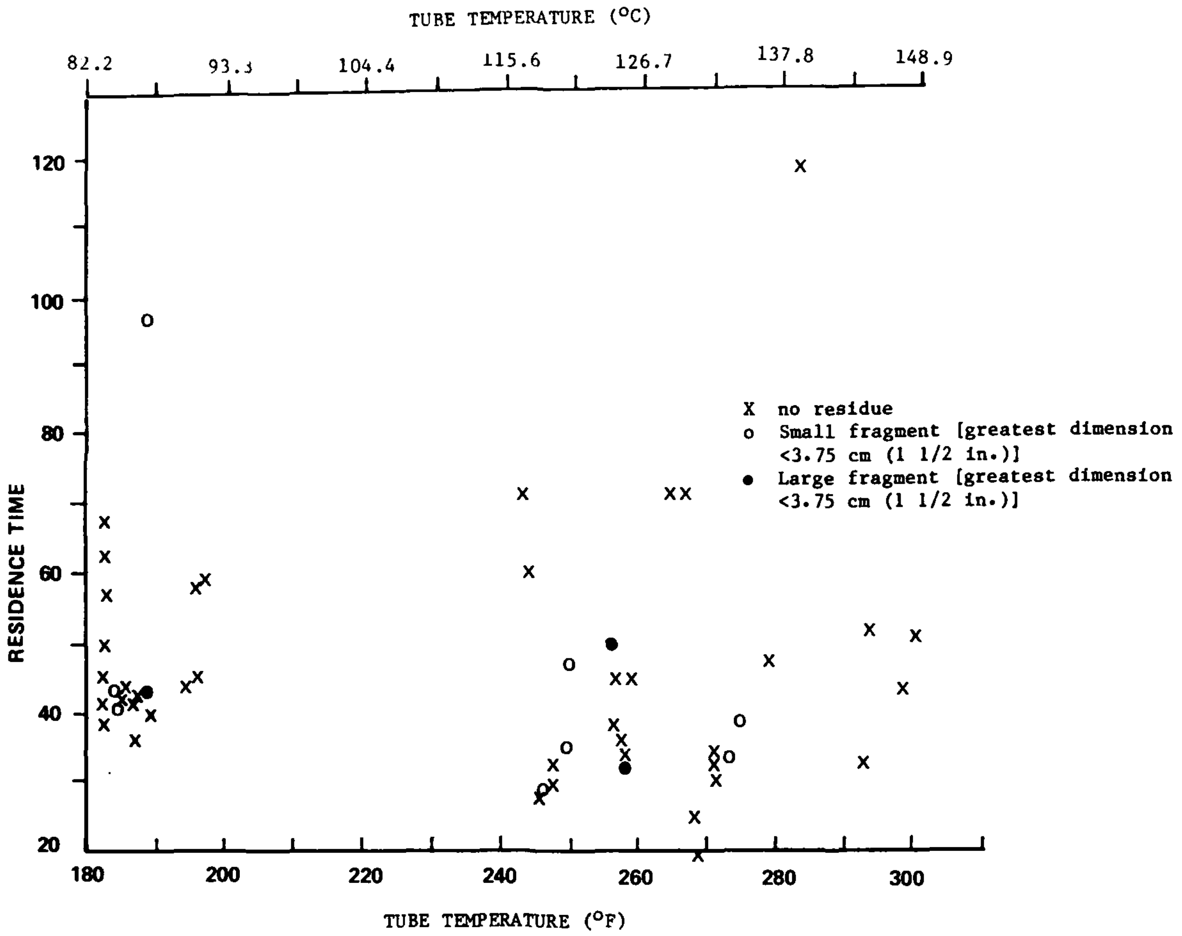


Figure 10. Chamber residence time, tube temperature, and occurrence of residue for Polywax 655 with rayon and lead laminate at 21°C (70°F)

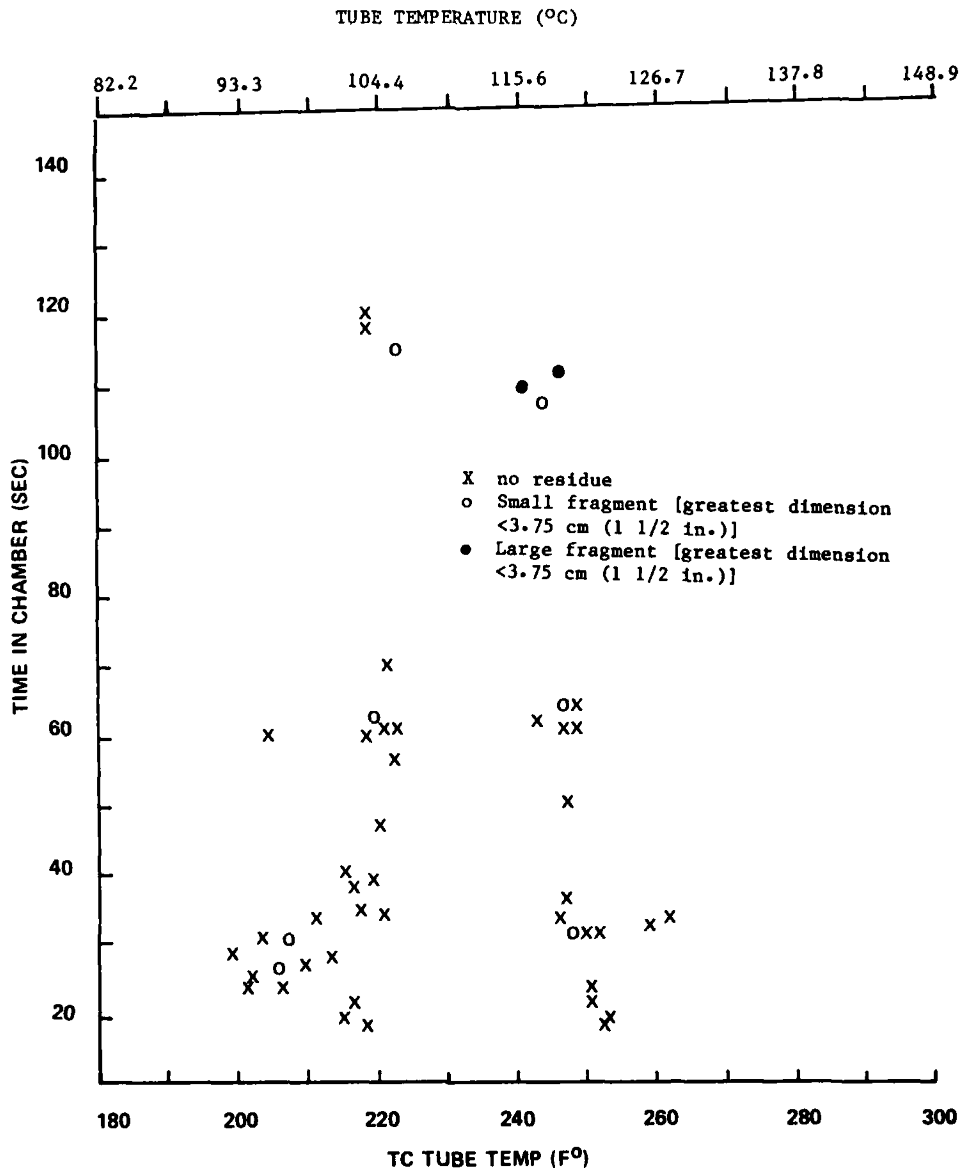


Figure 11. Chamber residence time, tube temperature, and occurrence of residue for Polywax 655 with rayon and lead laminate at 63°C (145°F)

APPENDIX A

LABORATORY INVESTIGATION OF WEAR ADDITIVE OF LINER VARIABILITY

INTRODUCTION

At the inception of this investigation, it was felt that the recurrence of the residue problem with 155 mm M203 propelling charges was due to manufacturing or materials variability. The laboratory investigation was designed to determine whether the wear preventing additive liners used in 155 mm M203 propelling charge lot 79A-69807, differed from liners tested in the Part I residue investigation. Using 170C wax in the liner produced substantially less residue for charges conditioned at 145°F and fired from a hot gun tube (160°F to 180°F). However, the 79A-69807 lot with the same type of liner showed a reoccurrence of residue under hot gun tube conditions.

PROCEDURES AND RESULTS

The laboratory test plan is given in Table A-1. The liner composition investigation and the liner and wax properties investigation screened the liner variability. The mechanical properties investigation related liner variablity to residue formation through liner strength. The molecular composition of liner components investigation determined liner variability on a molecular level.

Samples Analyzed

The samples analyzed are given in Table A-2 along with the date they were delivered to the laboratory. Most of the liners were taken from lot 79A-69807 charges stored at various locations. In some cases it was possible to determine whether these charges were from early or late production. Samples obtained from Aberdeen Proving Ground that were from early and late production were labeled APG 1, 2, 3 and APG 4, 5, 6, respectively. Samples obtained from Jefferson Proving Ground that were from early and late production were labeled JPG 1, 2, 3 and JPG 4, 5, 6, respectively. Samples obtained from Yuma Proving Ground were of unknown production time and were labeled YPG 1, 2, 3. Samples obtained from Indiana Army Ammunition Plant were of late production and were labeled IAAP 1, 2, 3, 4, 5. A liner from a charge using Indramic 170C in the Part I Residue Investigation was labeled R&D Liner. Additionally, an apparently intact liner fragment found among the residue from round number 1447 of the 15 May 1979 PVT was analyzed.

Various component materials used in liner manufacture were also analyzed. Wax samples A and B were two random samples of Indramic 170C wax. Wax samples W1 through W5 were taken from the Indiana AAP inventory of Indramic 170C used for liner manufacture in late May 1979. The Indiana AAP inventory of Indramic 170C differed substantially in color. Waxes W1 through W5 were picked to encompass the color differences found in the inventory and were labeled to indicate color gradation from light to dark. The low-molecular-weight polyethylene synthetic wax (Polywax 500 and 655), IRM wax (Japanese), and Shell 300 wax were also included in the test program.

Procedure

The composition of the liners was determined by separating the component of the liner. The wax was extracted from the liner u ing benzene. The residue was weighed and, then, the dacron staple was burned off in an oven to determine separately the TiO_2 content. Any stearyl alcohol present was determined along with the wax. The specified composition of the liner is: 46 ± 3% TiO_2, 53.5 ± 3% wax. 0.5 ± 0.25% dacron staple, and 0.5 ± 0.5% (advisory) stearyl alcohol. The procedures for melting point, oil content, penetration, exudation, and DSC were performed in accordance with MIL-W-20553D. The refractive index was determined using standard apparatus. Particle size of TiO_2 extracted from the wax was determined by microscopy. The mechanical strength tests were performed using an Instron Tester. Nuclear magnetic resonance (NMR) spectra of the waxes were obtained using a high resolution, pulsed Fourier Transform cryogenic facility. X-ray diffraction was performed using conventional apparatus.

RESULTS

Results of the laboratory investigation are summarized in tables A-3 through A-10.

DISCUSSION

Table A-3 lists the specifications for wax used in the M203 liners and also the value obtained by Holston AAP in January 1979 for the indramic 170C wax used in M203 Lot 79A-69807. Table A-4 gives a summary of the liner analysis except for the DSC data which are summarized in table A-5. The major conclusions from these data are:

1. While there is variability in the wax and liners, it is not possible to discern any significant difference between early and late production liners. The liners appear very similar to the liner used in Phase I testing of Indramic 170C and to the liner fragment taken from the residue.

2. There are two areas in which the liner is outside of specifications:

a. The dacron staple, in many cases, exceeds the specified limit of 0.75% (in one case, APG 3, it is 2.3%).

b. The exudation from the liners exceeds the specified maximum of 2.5% in every sample tested.

Since testing indicated that Indramic 170C did not meet the specifications, two alternate low-molecular-weight polyethylene synthetic waxes (Polywax 500 and 655) were included in the test program. The penetration data in Table A-9 indicate that the polywaxes are substantially harder than either Indramic 170C or Shell 300. The tensile strength of liner strips, which is given in Table A-6, was shown to be primarily related to the strength of the scrim material and is relatively constant.

The mechanical strength of Indramic 170C wax samples A and B is shown by the data in Table A-7 to be variable. However, since the samples may not have had the same preparation history, part of the discrepancy may be due to differences in the residual straining of the samples. Table A-8 gives differences in the measured compressive strengths with variation in sample components for light (W1) and dark (W5) wax. Stearyl alcohol weakens the liner; while, TiO_2 strengthens it.

The NMR analysis provided insight into the variability of Indramic 170C wax samples A and B. The CH_2, CH, and CH_3 carbon resonances were monitored. The relative intensity of these peaks are given in Table A-10. The ratio of CH/CH_2 indicates the relative chain branching. The data in Table A-10 also show that the relative chain branching (CH/CH_2 ratio) is less for wax B. Wax B has a higher proportion of straight chain (or more symmetrical) hydrocarbons; thus this sample has a higher melting point and is harder than wax A. X-ray diffraction data verified that the crystallite size is larger for sample B.

Table A-11 is a compilation of the properties of waxes used in this test program.

Table A-1. Laboratory test plan for analysis of waxes and liners

Liner composition:

TiO_2, wax, stearyl alcohol, dacron staple

Liner wax properties:

Melting point
Differential scanning calorimetry (DSC)
Refractive index
Oil content
Exudation
Penetration
TiO_2 particle size distribution

Mechanical properties of liners and liner wax:

Tensile strength of liners
Compressive strength of wax
Compressive strength of wax, TiO_2, and stearyl alcohol samples

Molecular composition of liner wax:

Nuclear magnetic resonance of wax samples

Table A-2. Liner and wax samples

Sample	Origin	Sample Number	Delivery Date
Liners	APG	1 through 6	5/9/79
Liner	R&D charge	R&D liner	5/9/79
Liners	JPG	1 through 6	5/9/79
Liners	YPG	1 through 3	5/9/79
Wax	Indramic	A, B	5/9/79
Liners	IAAP	1 through 5	5/15/79
Wax	IAAP	W1 through W5	5/22/79
Liner	Residue from round 1447	Liner fragment	5/22/79

Table A-3. Wax desensitizing -- MIL-W-20553D

Property	Specifications	Indramic 170C (Holston 1/21/79)
Melting point (^{o}F min)	175	176.4
Melting point (^{o}F max)	200	-
Viscosity at 210^{o}F (SUS)	15 ± 6	16.2
Min penetration at 77^{o}F (0.1 mm)	6	14
Max penetration at 110^{o}F (0.1 mm)	35	28
Max oil content (%)	2.5	1.2
Max exudation at 160^{o}F (%)	3.0	2.4
Fingerprint DSC	Compare to 1973 standard	OK compared to std

Table A-4. Average compositions and properties of liners

Item	Source and number of samples[b]									
Composition (%)[a]	IAAP 5		JPG 6		YPG 3		APG 6		R&D 1	Residue 1
Wax and alcohol	54.7	(0.3)	53.3	(0.9)	54.8	(1.6)	54.5	(0.9)	56.6	54.3
TiO_2	45.3	(0.3)	45.7	(0.7)	45.0	(1.3)	44.7	(1)	42.8	45.7
Dacron	1.1	(0.2)	1.2	(0.3)	1.0	(0.2)	1.1	(0.7)	0.64	0.85
Properties										
Wax MP (°F)	175	(2)	176	(2)	175	(2)	176	(2)	175	176
Oil content (%)	2.4	(0.4)	3.1	(0.4)	2.5	(1.7)	2.7	(1.1)	2.2	3.1
Penetration (0.1 mm)	18	(5)	20	(7)	27	(7)	24	(5)	50	22
Refractive index	1.4414		1.4404		1.4416		1.4403		1.4405	1.4405
Liner exudation (%)	7.9	(3.2)	9.5	(6.5)	11.1	(2.8)	11.2	(3.4)	6.1	7.7
TiO_2										
Particle size (μ)	22	(2)	20	(2)	21	(2)	20	(2)	23	20

[a]No measurable stearyl alcohol existed in any sample.

[b]Values in parentheses show standard deviation.

Table A-5 Data from DSC of waxes

	I.T. (°C)	Solidification point (°C)	Liquefication poin* (°C)	Heat of fusion (cal/g)	Relative* softness at 110°F
IAAP					
W1 Lab	18.3	75.9	84.2	31.64	28.3
W2 Lab	16.8	75.0	83.8	31.45	26.2
W3 Lab	15.8	75.0	83.2	31.31	32.3
W4 Lab	17.4	74.9	83.4	31.23	26.5
W5 Lab	18.0	74.0	83.2	30.51	28.4
Shell 300					
PO22590	25.0	66.8	74.0	39.94	8.0
IRM (Japanese)					
DO-27236	31.6	65.2	72.2	42.31	6.3
Jefferson no. 4	15.0	73.6	82.9	28.32	59.9
Jefferson no. 5	15.2	73.8	83.3	27.78	58.7
Jefferson no. 6	15.9	73.8	82.6	28.98	--
Spent liner wax	15.6	73.7	82.9	29.68	52.0
HI MP liner wax (rerun of 1)	15.0	73.7	82.6	28.76	62.1
HI MP wax A	15.6	75.9	84.8	29.15	32.9
HI MP wax B	20.4	75.8	84.3	28.14	13.7
HI MP wax extract	18.0	74.8	83.8	21.78	29.4
Aberdeen no. 1	15.8	74.6	83.6	24.73	36.4
Aberdeen no. 2	15.9	76.0	85.0	28.31	40.9

*Calculated from the relation: deflection (mm) x scan rate (°C/mm) per wt sample (mg).

Table A-5 Data from DSC of waxes (cont)

	I.T. (°C)	Solidification point (°C)	Liquefication point (°C)	Heat of fusion (cal/g)	Relative* softness at 110°F
Aberdeen no. 3	16.2	76.4	85.7	30.44	40.4
Aberdeen no. 4	16.0	75.4	84.7	33.76	36.1
Aberdeen no. 5	16.3	76.4	86.1	29.92	29.0
Aberdeen no. 6	17.0	75.9	84.3	30.02	30.5
Yuma no. 1	16.0	75.1	83.7	26.64	32.4
Yuma no. 2	15.6	76.6	85.8	27.80	30.8
Yuma no. 3	16.3	76.4	85.7	29.49	27.2
Jefferson no. 1	15.7	74.6	82.9	25.94	41.7
Jefferson no. 2	16.5	74.8	84.4	27.75	32.6
Jefferson no. 3	16.4	74.0	84.5	28.87	48.7
IAAP no. 1	16.0	74.5	84.2	28.86	39.8
IAAP no. 2	15.9	74.8	83.9	30.48	43.6
IAAP no. 3	15.0	77.5	86.2	30.08	37.8
IAAP no. 4	15.5	75.5	85.1	29.00	33.3
IAAP no. 5	16.1	73.5	84.3	31.02	26.8

*Calculated from the relation: deflection (mm) x scan rate (°C/mm) per wt sample (mg).

Table A-6. Tensile strength of liner strips

Sample	No. of samples	Breaking load (lb)	Standard deviation (lb)
APG 1	6	73	8
JPG 1	4	77	5
YPG 1	4	77	5

1 x 6 1/4 in. sample strips, 23 - 27 threads/in., lead removed, 0.21 IPM

Table A-7. Compressive strength of wax samples*

Sample	No.	Peak load (lb)		Compression strength (PSI)	Standard deviation (PSI)
A	4	23.9	0.5	150.7	3.3
B	3	39.6	0.3	249.1	1.6

*Samples: Indramic 170C, 0.45 x 0.52 in. cylinders
Conditions: Instron (compression), 0.1 IPM, $85^{o}F$

Table A-8. Compressive strength of Indramic 170C waxes (W1 and W5) (PSI)

Light wax (W1)	Light wax (W1) with stearyl alcohol
524	477
458	482
---	471

Dark wax (W5)	Dark wax (W5) with stearyl alcohol
377	416
399	434
419	---

Dark wax (W5) with TiO_2	Dark wax (W5) with TiO_2 and stearyl alcohol
1131	791
1082	801
----	881

Table A-9. Penetration (110°F) 0.1 mm

Shell 300	33
Indramic 170C	45
Polywax 500	21
Polywax 655	7

Table A-10. Comparison of molecular properties -- wax samples A and B

Sample	Peak intensity A (CH_2)	Peak intensity B (CH)	Peak intensity C (CH_3)	Relative chain branching (NMR)	M. P. (^oF)	Relative strength
A	1	1	1	1	175.8	1
B	1	0.79	0.96	0.80	178.5	1.65

Table A-11. Properties of waxes used in the residue test program

Properties	Test	Indramic 170C, sample A	Indramic 170C, sample B	Polywax 500, batch 15684	Polywax 655, batch 15582
Melting point (^{o}F)	ASTM D 127	176	176	191	211
Flash (^{o}F)	ASTM D 92	535	535	475	540
Viscosity					
at 210^{o}F (SUS)	ASTM D 88	73	70	60	---
at 210^{o}F (CST)	ASTM D 2161	13.7	13.0	10.2	---
at 300^{o}F (SUS)	ASTM D 88	-----	-----	40	47
Penetration	ASTM D 1320				
at 77^{o}F (0.1 mm)		15	12	6	3
at 110^{o}F (0.1 mm)		68	47	21	7
Oil Content (%)	ASTM D 721	1.02	0.76	0.39	0.3

APPENDIX B

TRANSPORTATION VIBRATION AND ROUGH HANDLING TESTS FOR PROPELLING CHARGES M203 CONTAINING POLYWAX 655

In preparation for the final engineering tests which qualified the Polywax 655, 10 charges each from the U and V groups were preconditioned at -60°F (cold charges) and 10 charges from each group were preconditioned at 145°F (hot charges). The U group used scrim backing, and the V group used rayon and lead laminate backing.) All 40 charges were then subjected to Logistical Transportation (TV) tests specified by TOP 1-2-601. After the TV tests, three hot charges from each group and three cold charges from each group were broken down and examined. Photographs of the liners and center core tubes after being subjected to TV tests are shown in figures B-1 through B-6. The wax side of the liners was cracked, as expected, but very little wax was actually missing. The lead was torn and wrinkled from being rubbed, but it was all in place. Although all the center core tubes looked good and none were physically damaged, two tubes were bowed about 1/2 in. — which is more than the 1/8 in. permitted by the technical data package. However, none of the defects observed would be expected to adversely affect the functioning of the M203 charge.

The remaining 28 charges (14 from group U and 14 from group V) were then subjected to the Bounce Test [Rough Handling (RH)] as specified by TOP 2-4-602. Three charges from each group of seven were broken down and examined. Photograhs of the liners and center core tubes after being subjected to both TV and RH tests are shown in figures B-7 through B-14. These figures show that more of the liner material was loosened because of the RH tests, particularly for charges preconditioned at -60°F. Also the U group (scrim backing) showed more severe liner damage than the V group (rayon and lead laminate backing). For the U group the lead foil was badly stripped, torn, and balled up -- again, particularly for charges preconditioned at -60°F. The tubes showed no additional defects as a result of the RH tests (four tubes had a similar degree of bowing as described above). Again, none of the defects observed would be expected to adversely affect the functioning of the M203 charge.

The remaining four charges from each group of seven were fired at -60°F and at +145°F in a tube having a temperature of less than 200°F (cool tube). The ballistics were normal, and there was no residue with these charges.

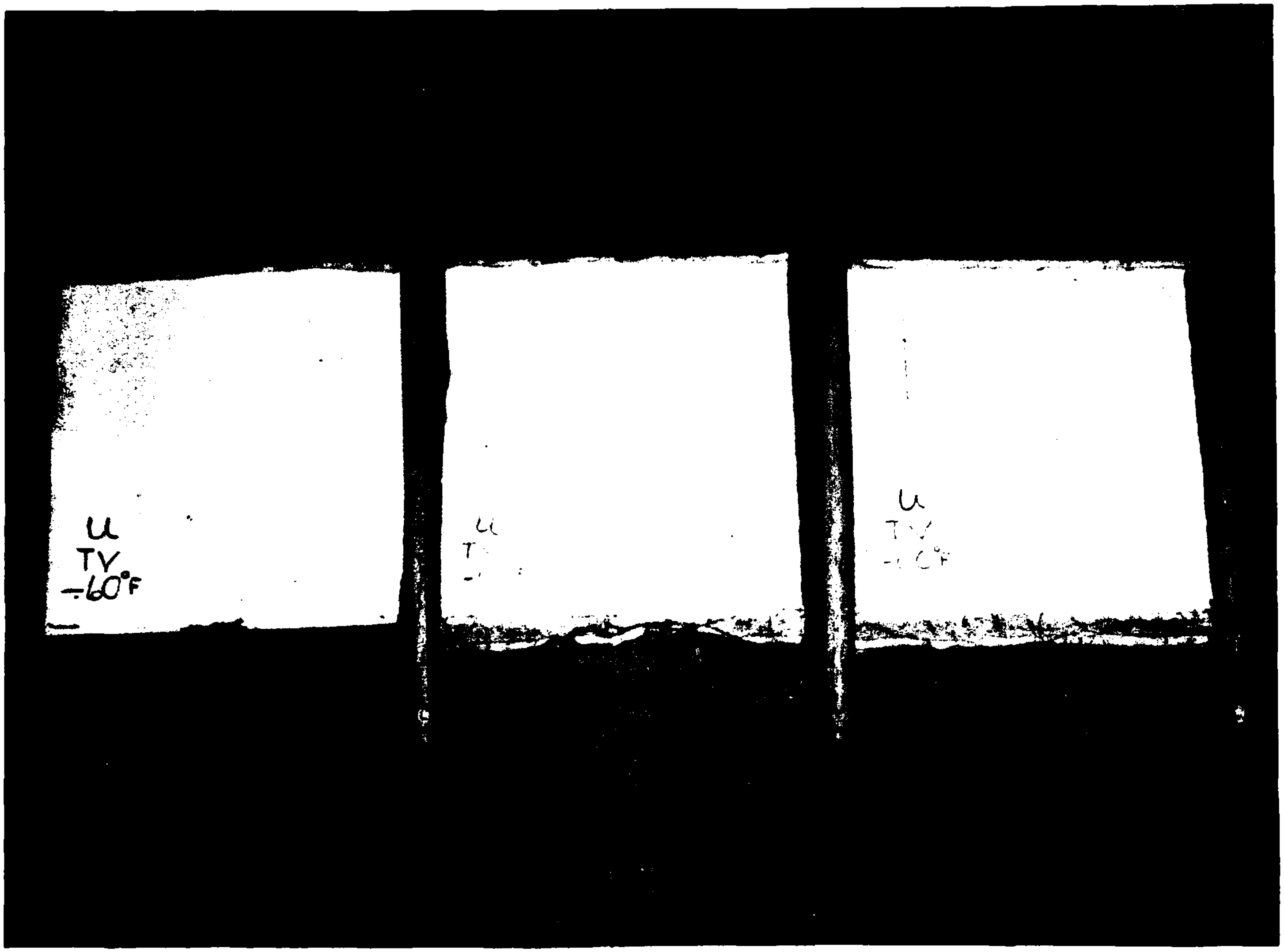


Figure B-1. Group U liners and tubes from cold charges after TV tests -- wax side

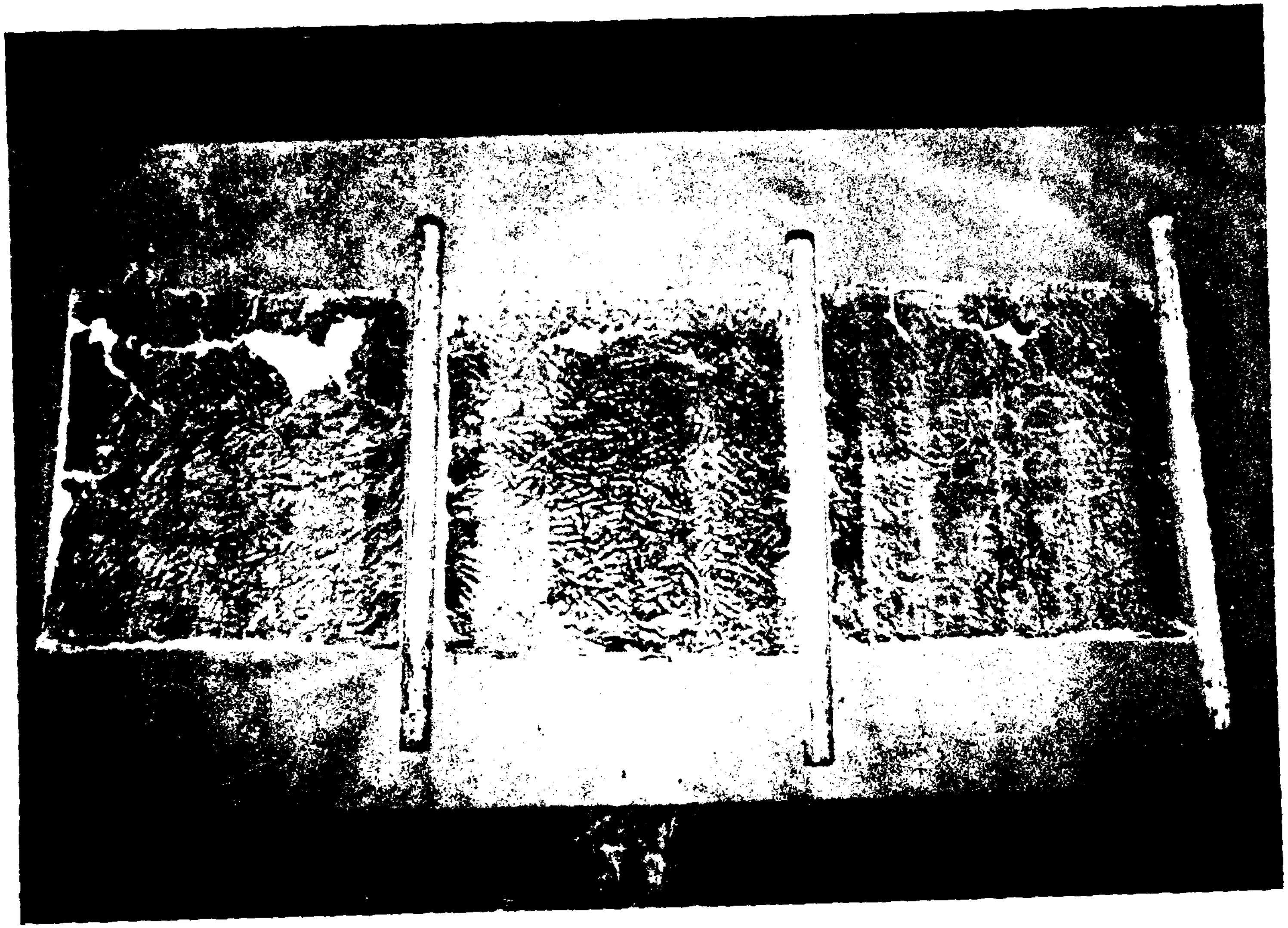


Figure B-2. Group U liners and tubes from cold charges after TV tests -- foil side

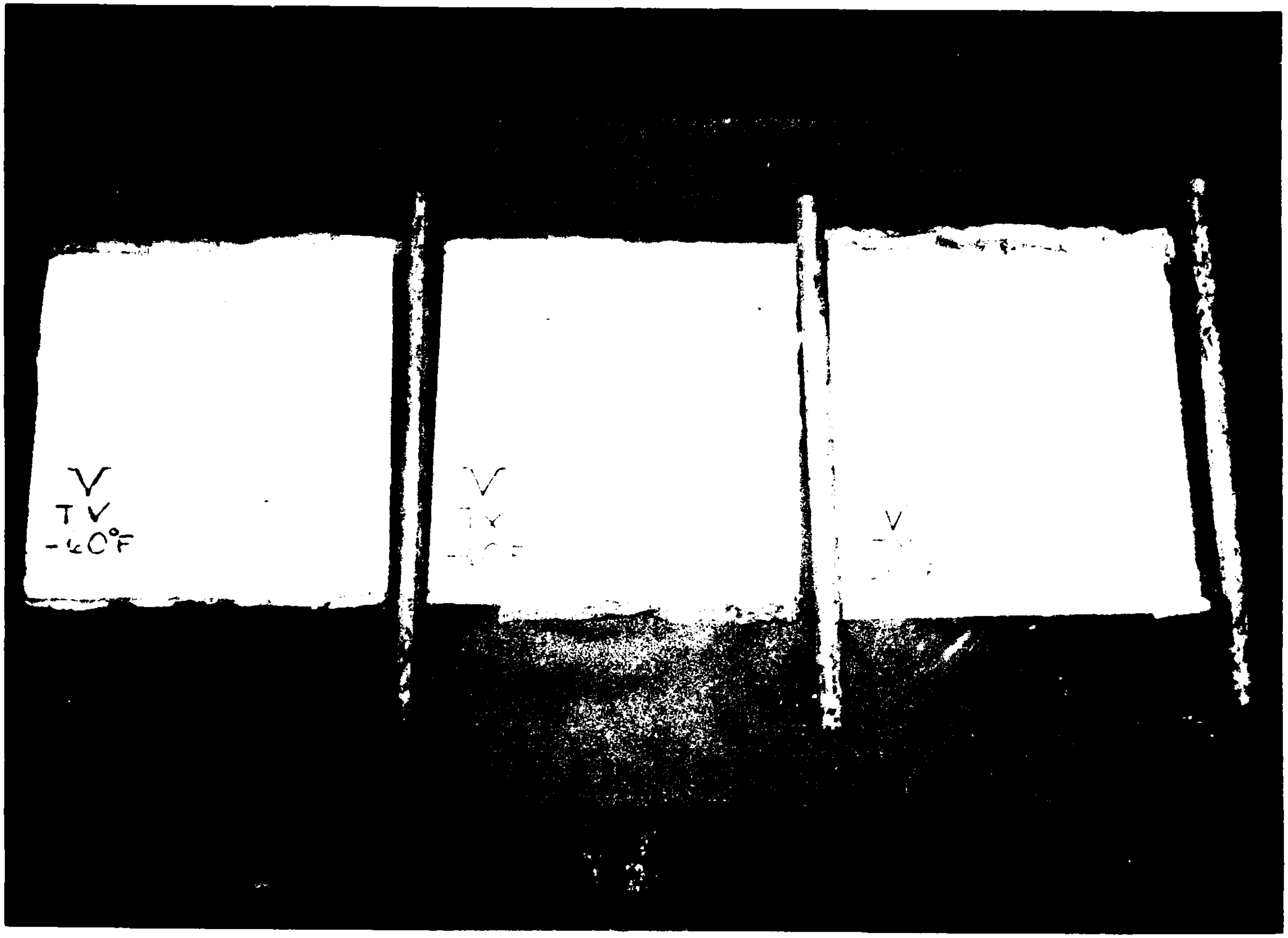


Figure B-3. Group V liners and tubes from cold charges after TV tests -- wax side

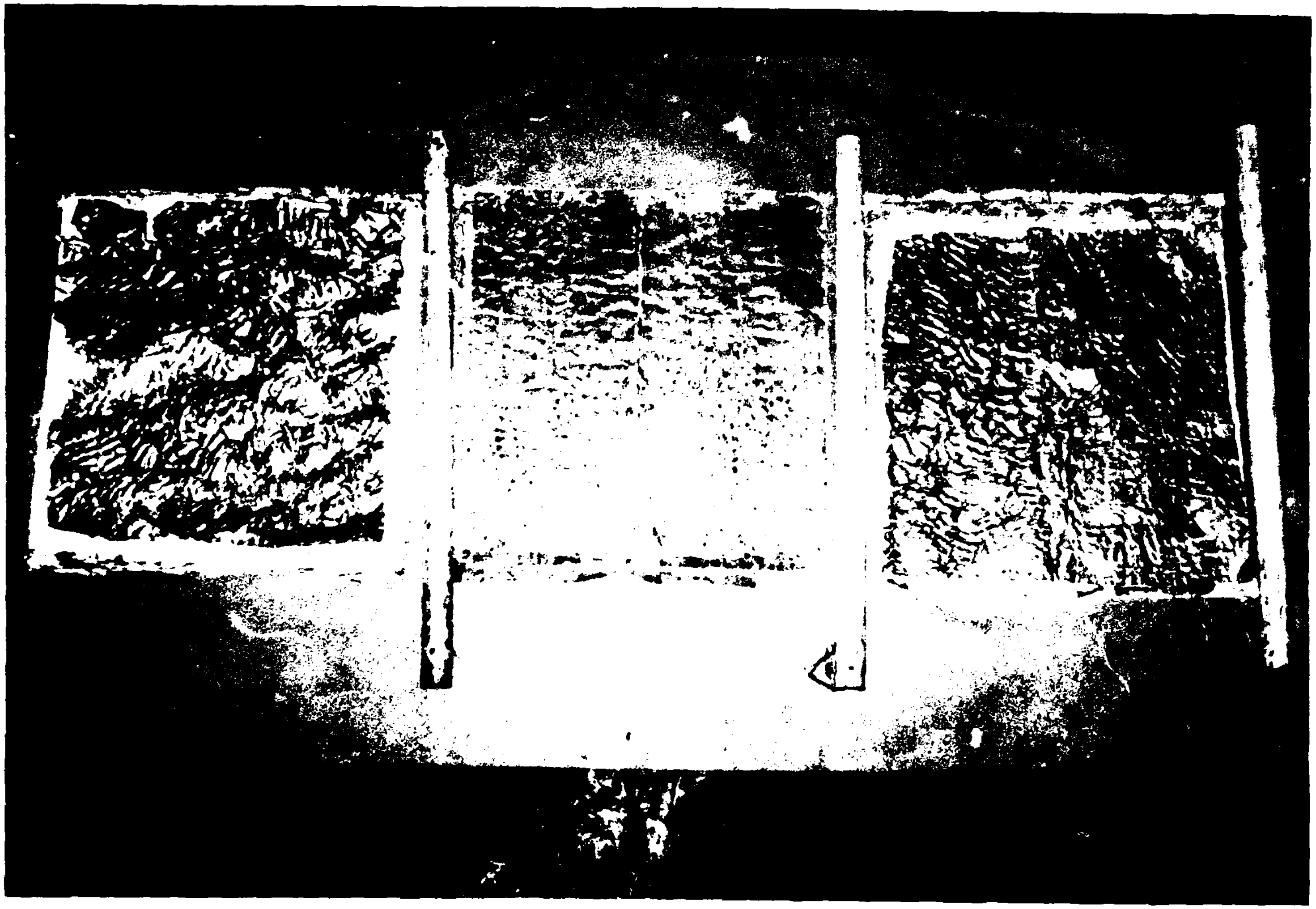


Figure B-4. Group V liners and tubes from cold charges after TV tests -- foil side

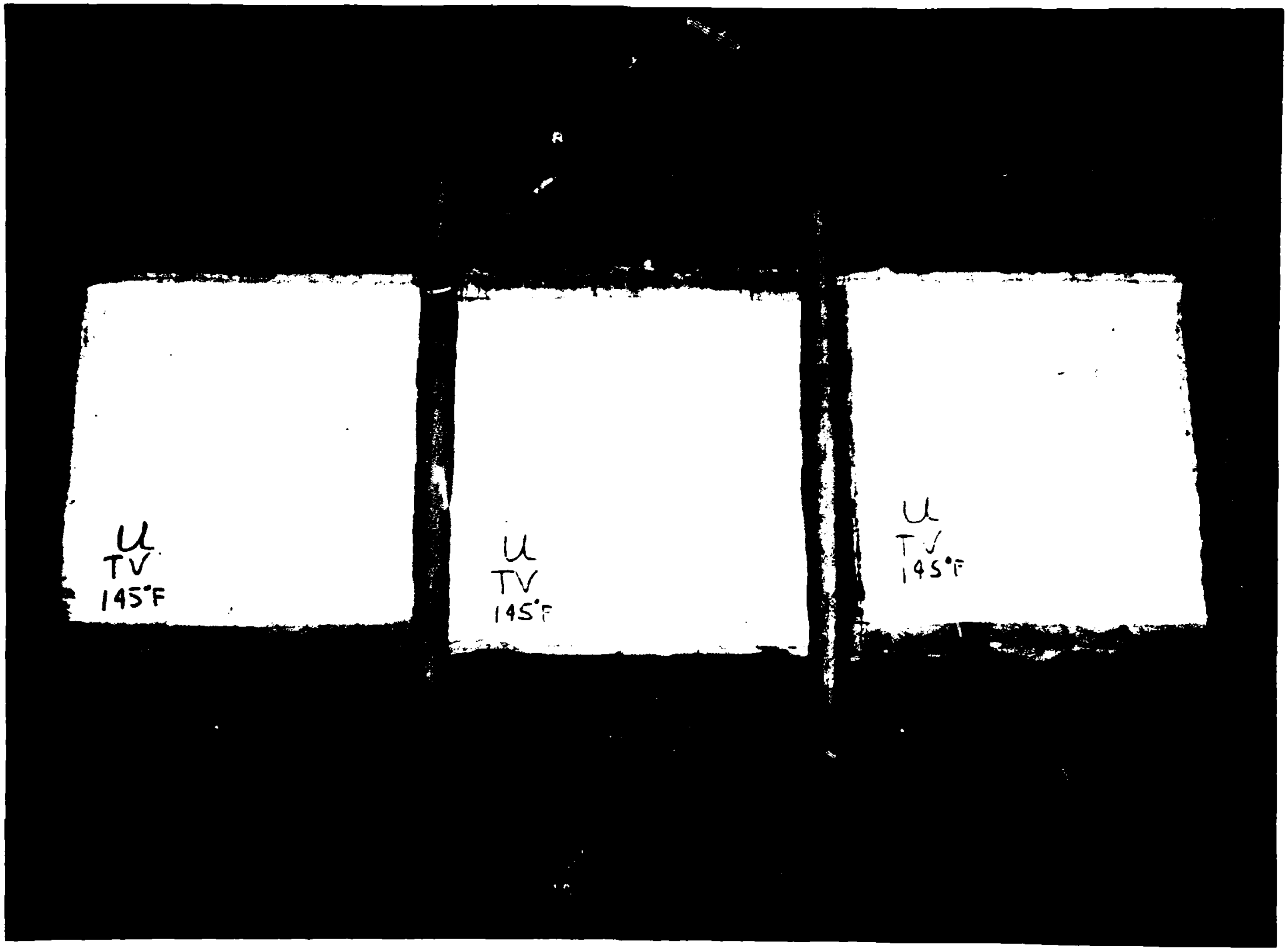


Figure B-5. Group U liners and tubes from hot charges after TV tests -- wax side

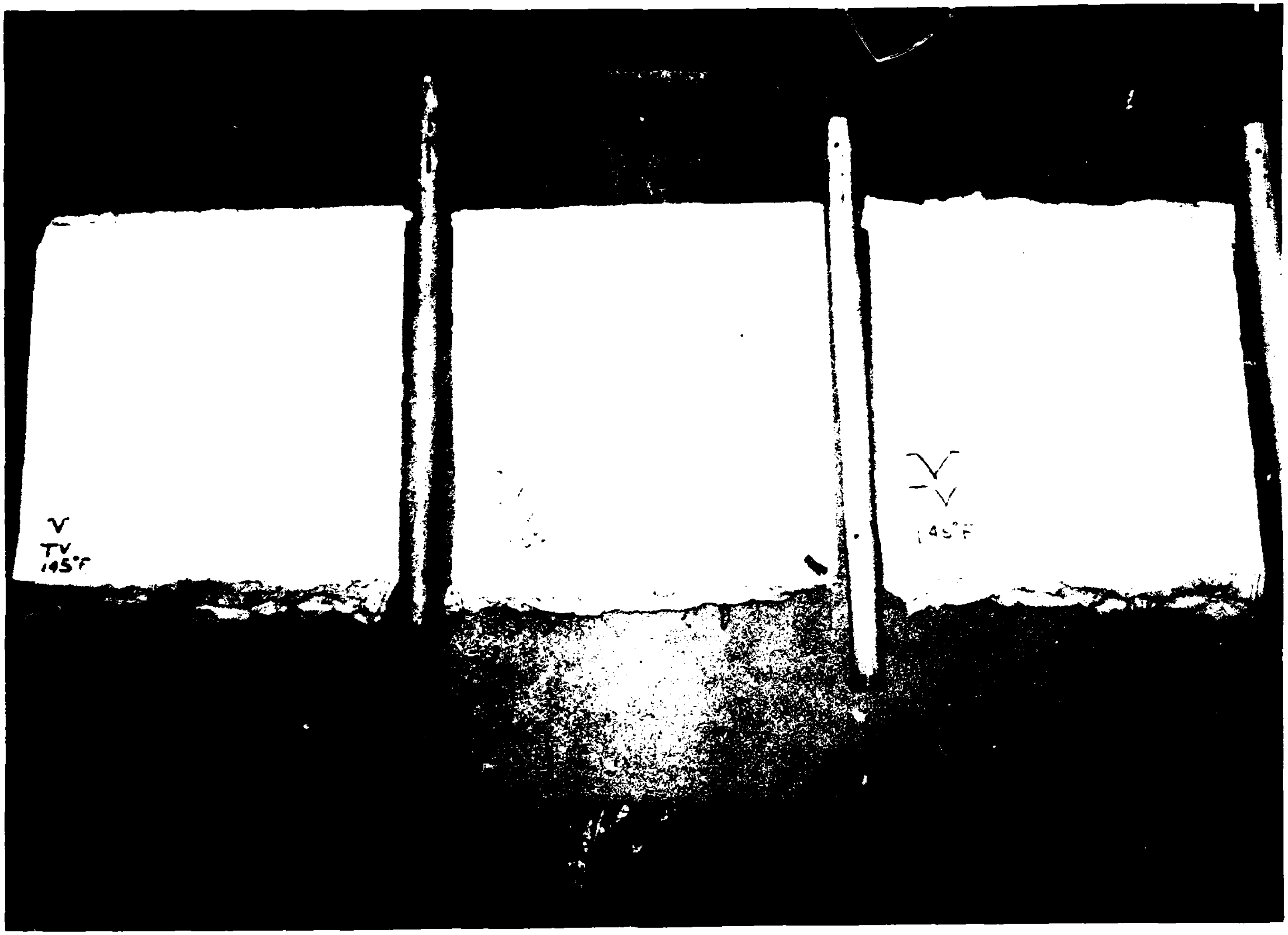


Figure B-6. Group V liners and tubes from hot charges after TV tests -- wax side

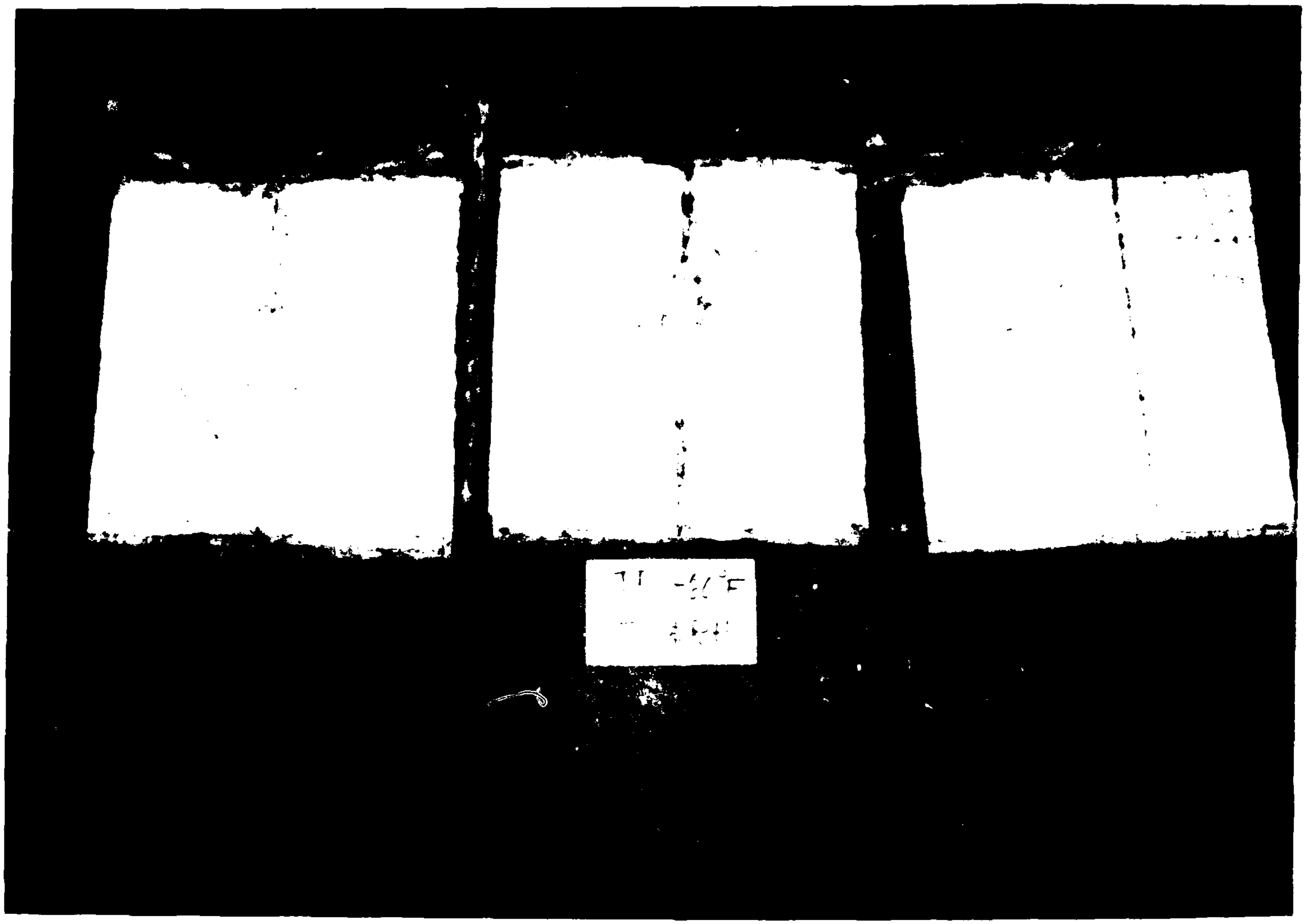


Figure B-7. Group U liners and tubes from cold charges after TV and RH tests -- wax side

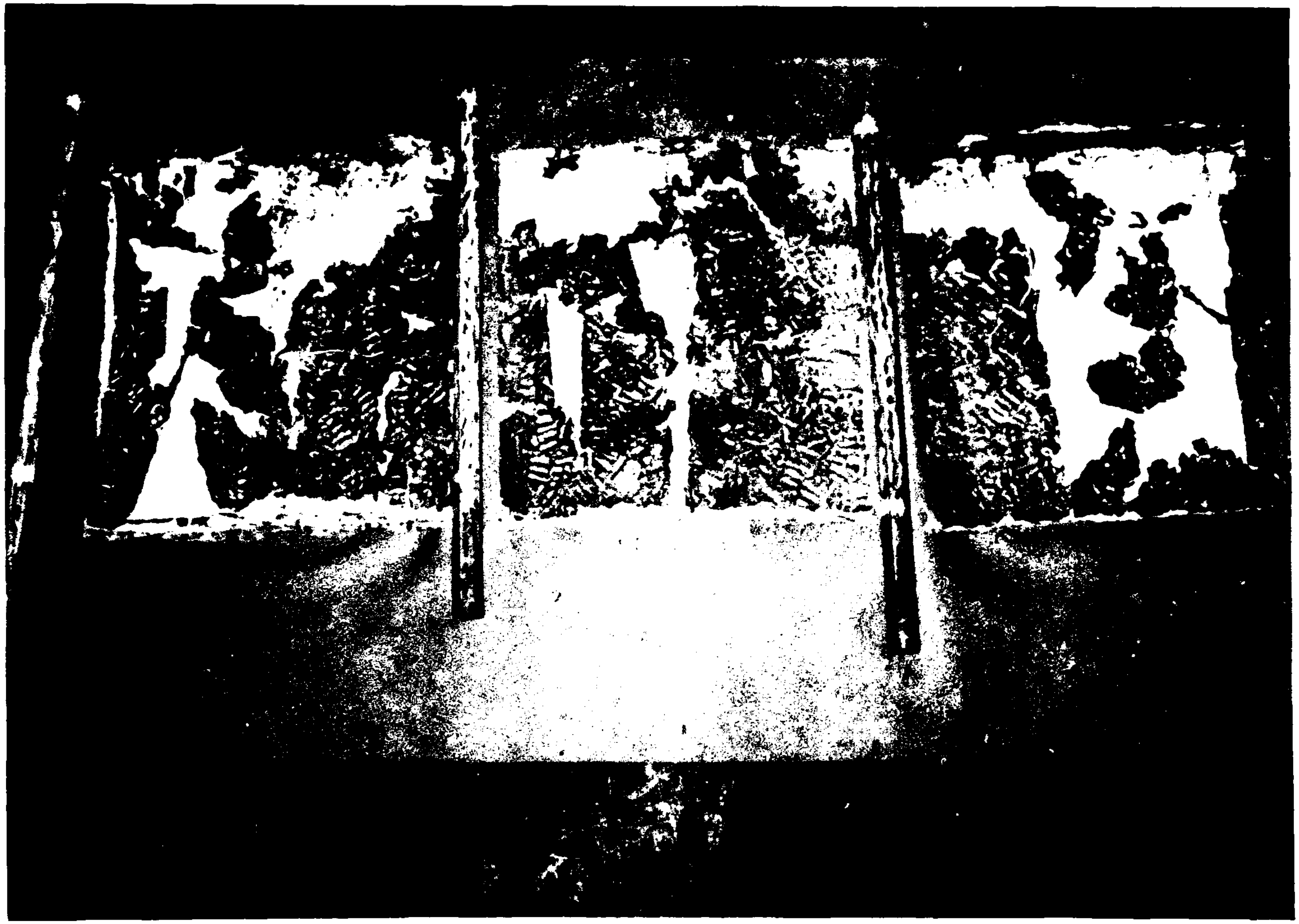


Figure B-8. Group U liners and tubes from cold charges after TV and RH tests — foil side

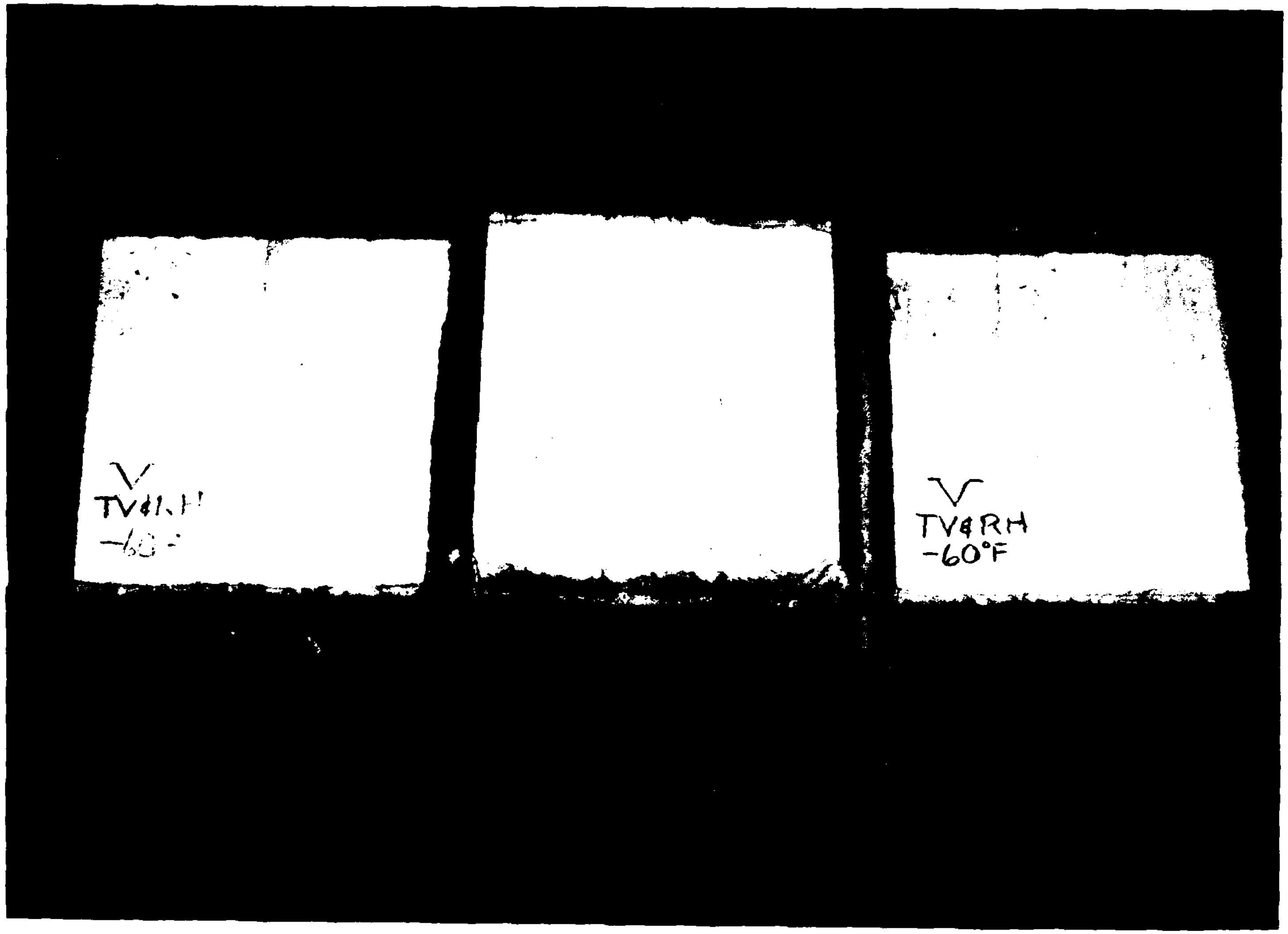


Figure B-9. Group V liners and tubes from cold charges after TV and RH tests -- wax side

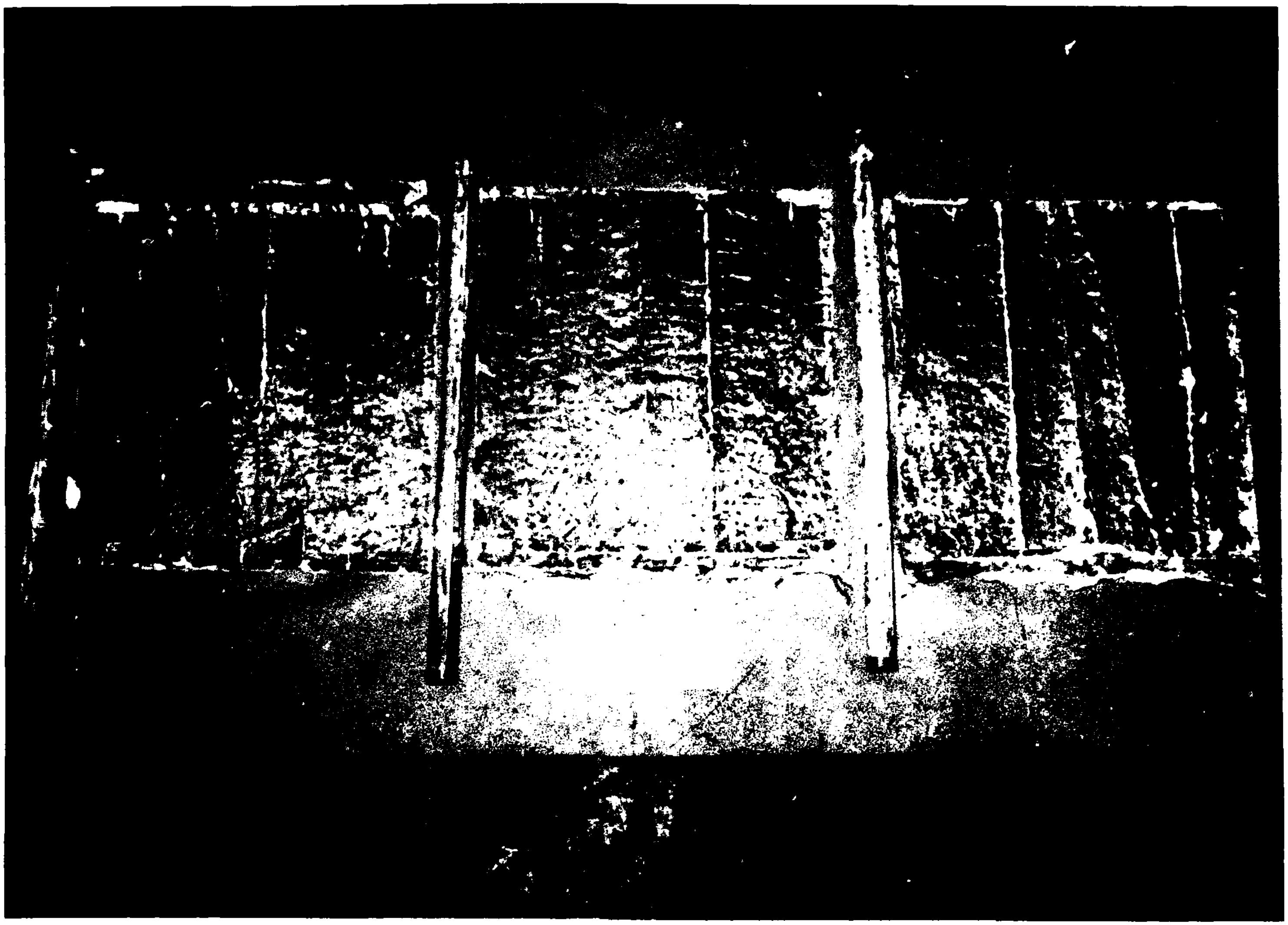


Figure B-10. Group V liners and tubes from cold charges after TV and RH tests -- foil side

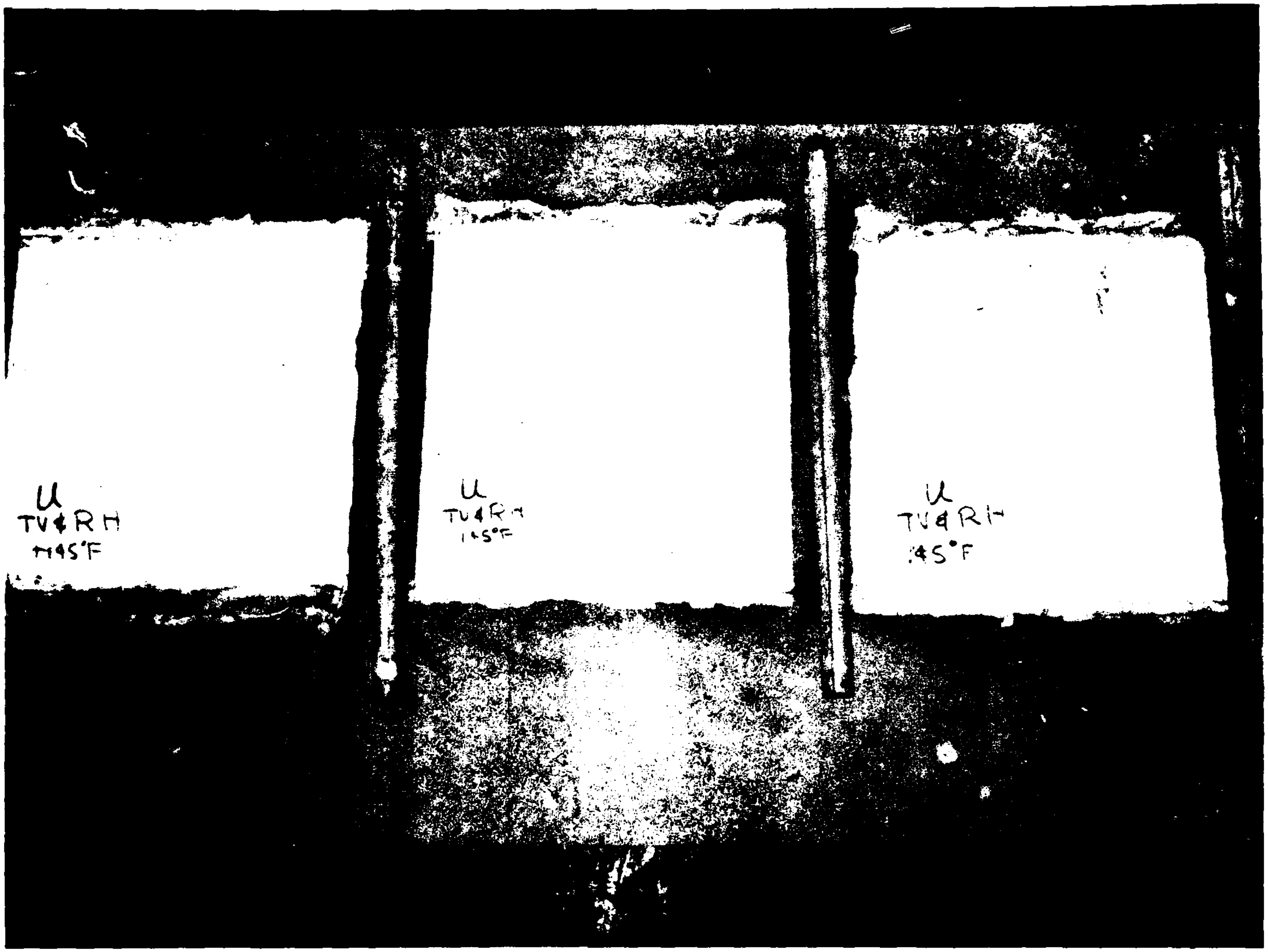


Figure B-11. Group U liners and tubes from hot charges after TV and RH tests -- wax side

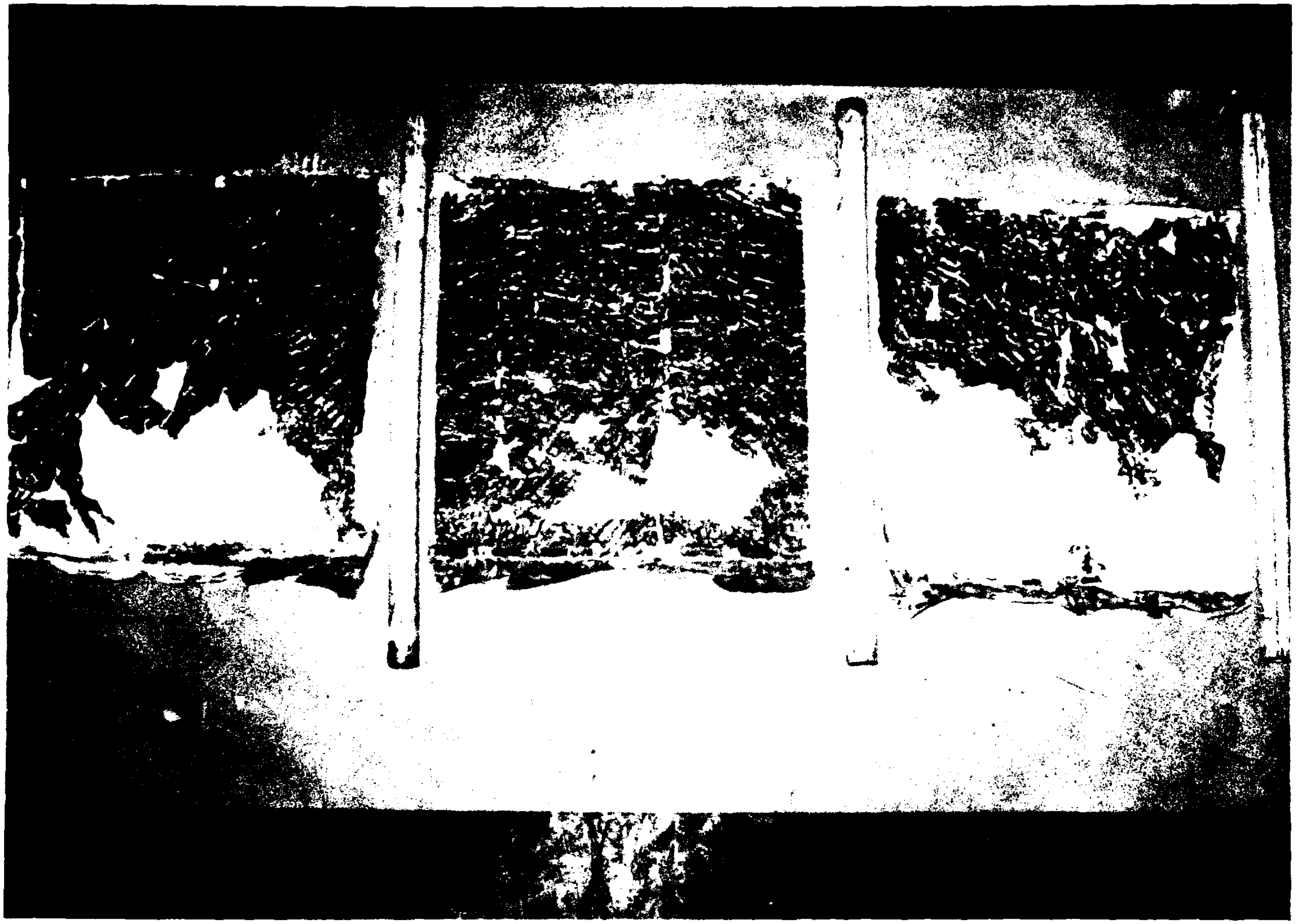


Figure B-12. Group U liners and tubes from hot charges after TV and RH tests -- foil side

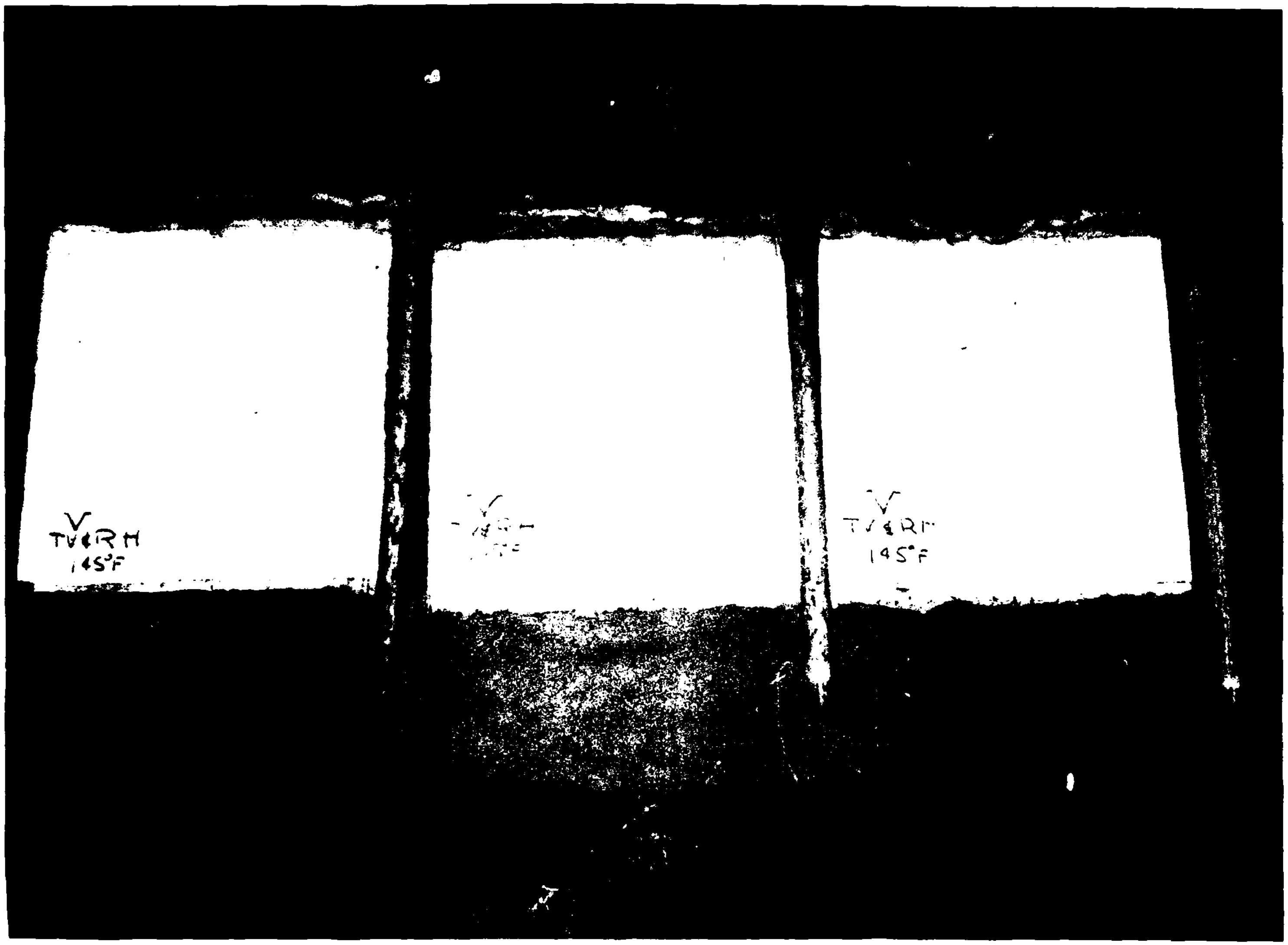


Figure B-13. Group V liners and tubes from hot charges after TV and RH tests -- wax side

Figure B-14. Group V liners and tubes from hot charges after TV and RH tests — foil side

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8